EXHIBIT A

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICANT(s):	John A. Samuels	CONF. NO.:	8407
SERIAL NO.:	09/902,193	ART UNIT:	2614
FILING DATE:	07/10/2001	EXAMINER:	Knowlin, Thjuan P.
TITLE:	METHOD AND APPARATUS FOR TRANSMITTING AND RECEIVING SIGNALS		
ATTORNEY DOCKET NO.:	200-007752-US(D01)		

Mail Stop AF
Commissioner of Patents
P.O. Box 1450
Alexandria, VA 22313-1450

SUPPLEMENTAL DECLARATION UNDER 37 C.F.R. 1.131

I, John A. Samuels, declare that I am the inventor in the above-identified United States patent application (present application) and in a parent United States application of which priority is claimed in the present application. I declare hereby further that:

The present application, having application number 09/902,193 and filing date of July 10, 2001, is a division of parent application 08/994,228 filed on December 19, 1997.

I conceived the invention set forth in the claims of said present application in Great Britain, which is a WTO country, at a time prior to December 20, 1996, which date is the filing date of Enoki U.S. patent 5,835,853 used by the examiner in rejecting claims of said present application under 35 U.S.C. 102 and 103 as set forth in an Office Action dated September 22, 2005 and in a subsequent Office Action dated May 15, 2006.

Said invention is disclosed in the text and figures of a patent application (British application) filed in Great Britain on December 23, 1996 and identified by application number 9626732.3. A copy of said British Application, including the specification and drawing figures plus signed and dated papers accompanies this declaration and is identified as Exhibit "A". Said parent application claims priority, under 35 U.S.C. 119, of said British application.

A first one of the signed papers is a form of the British Patent Office, entitled "Statement of inventorship and of right to grant of a patent", is signed by J M Potter as agent for the applicant, and is dated on the twentieth day of December 1996. This paper also bears the name James Seymour as a person who may be contacted by the British Patent Office.

A second one of the signed papers is a form of the British Patent Office, entitled "Request for a preliminary examination and search", is signed by J M Potter as agent for the applicant, and is dated on the twentieth day of December 1996. This paper also bears the name of said James Seymour as a person who may be contacted by the British Patent Office.

The textual portion and the figures of said British application describing said invention have been in existence from a time prior to December 20, 1996.

During the period extending from a time prior to December 20, 1996 until December 23, 1996, said James Seymour, who works as a patent attorney in the Intellectual Property Rights department of Nokia Mobile Phones Limited, which is the assignee of said present and parent U.S. applications, attended to the performance of tasks in Great Britain relating to the filing of the British application, these tasks including preparing an initial draft of the application describing the technical implementation of said

invention, presenting the application to the inventor for review, and editing the application.

I believe that the description set forth in said textual portion and said figures of said British application show conception of said invention at a time prior to December 20, 1996, and that said tasks performed by James Seymour during said period extending from the time prior to December 20, 1996 until December 23, 1996 with the filing of the British application on December 23, 1996, and followed by the subsequent filing of said U.S. parent application on December 19, 1997 claiming priority in the British application show diligence from the time prior to December 20, 1996 until the filing of said parent U.S. application.

And I believe further that this showing of conception prior to the filing date of Enoki U.S. patent 5,835,853 with diligence until the filing of said parent U.S. application overcomes the aforementioned rejections under 35 U.S.C. 102 and 103 so as to secure allowance of the claims in said present U.S. application.

I declare further that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of this application or any patent issued thereon.

Respectfully submitted,

J. A. Samuels   29.11.06

John A. Samuels   Date

The Patent Office
Cardiff Road
Newport
Gwent
NP9 1RH
Tel: 01633 814571

Receipt for Documents for a Patent Application

Documents for a patent application have been received and recorded under the provisions of the Patents Act 1977 in the name(s) shown below.

The documents bear this number which should be used on all correspondence concerning them. 9626732·3

The filing date provisionally given to the application is 23 DEC 1996

Applicants:
NOKIA MOBILE PHONES LIMITED.

Document date: 23.12.1996
Application filing, "Application"
NC13406 GB 9/9

THE DOCUMENTS RECEIVED PURPORT TO BE:

REQUEST FOR GRANT OF A PATENT	✓
DESCRIPTION	✓
CLAIMS	✓
DRAWINGS (No. of Sheets)	13 + 13
ABSTRACT	✓
STATEMENT OF INVENTORSHIP (Form 7/77)	✓
REQUEST FOR SEARCH (Form 9/77)	✓
PRIORITY DOCUMENT(S) (No. of Documents)	x
TRANSLATION(S) OF PRIORITY DOCUMENT(S) (No. of Documents)	x
REQUEST FOR EXAMINATION (Form 10/77)	x
OTHER (Specify) TWO Copies of PAT 96014 GB	✓
ANNEX A.	x
	x

Address for service

DR. J M POTTER
PATENT DEPT.
NOKIA MOBILE PHONES
ST. GEORGES COURT
ST. GEORGES ROAD
CAMBERLEY SURREY GU15 3QZ

D. Clinton 7/1/97.
Signature & Date

Agent's Reference
PAT 96035 GB

NB – Issue of this receipt does not confirm that the documents received are sufficient to meet the filing conditions under Section 15(1) or the relevant conditions under Section 89A(3)

FORM P.Ack 4 (8/95)

Patents Form 1/77

Patents Act 1977
(Rule 16)

The Patent Office

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

1. Your reference

PAT 96035 GB

2. Patent application number
(The Patent Office will fill in this part)

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

NOKIA MOBILE PHONES LIMITED
PO BOX 86
SF 24101
SALO
FINLAND

Patents ADP number *(if you know it)*

If the applicant is a corporate body, give the country/state of its incorporation

FINLAND

4. Title of the invention

METHOD AND APPARATUS FOR TRANSMITTING AND RECEIVING SIGNALS

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

DR. J M POTTER
PATENT DEPT.
NOKIA MOBILE PHONES
ST. GEORGES COURT
ST. GEORGES ROAD
CAMBERLEY, SURREY
GU15 3QZ

Patents ADP number *(if you know it)*

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
See note (d))

YES

Patents Form 7/77

Patents Act 1977
(Rule 15)

The Patent Office

Statement of inventorship and of right to grant of a patent

The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

1. Your reference — PAT 96035 GB

2. Patent application number
(If you know it)

3. Full name of the or of each applicant — NOKIA MOBILE PHONES LIMITED
PO BOX 86
SF-24101
SALO, FINLAND

4. Title of the invention — METHOD AND APPARATUS FOR TRANSMITTING AND RECEIVING SIGNALS

5. State how the applicant*(s)* derived the right from the inventor*(s)* to be granted a patent — BY VIRTUE OF SECTION 7(2)(c)

6. How many, if any, additional Patents Forms 7/77 are attached to this form?
(see note (c))

7. I/We believe that the person*(s)* named over the page *(and on any extra copies of this form)* is/are the inventor*(s)* of the invention which the above patent application relates to.

Signature
DR J M POTTER
AGENT FOR THE APPLICANT

Date 20.12.1996

8. Name and daytime telephone number of person to contact in the United Kingdom — JAMES SEYMOUR - 01276 419606

Notes

a) If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.

b) Write your answers in capital letters using black ink or you may type them.

c) If there are more than three inventors, please write the names and addresses of the other inventors on the back of another Patents Form 7/77 and attach it to this form.

d) When an application does not declare any priority, or declares priority from an earlier UK application, you must provide enough copies of this form so that the Patent Office can send one to each inventor who is not an applicant

e) Once you have filled in the form you must remember to sign and date it.

Patents Form 9/77

Patents Act 1977
(Rules 25, 28 & 32)

The Patent Office

Request for a preliminary examination and search

(See the notes on the back of this form)

The Patent Office

Cardiff Road
Newport
Gwent NP9 1RH

1. Your reference — PAT 96035 GB

2. Patent application number
(if you know it)

3. Full name of the or of each applicant — NOKIA MOBILE PHONES LIMITED

4. Is this request for:

   a) A preliminary examination and search under Section 17(1)? — (a)

   b) A supplementary search under Section 17(8)?

   c) A search of a further invention under Section 17(6)?

   (Answer this question by writing (a), (b) or (c).)
   If your answer is (c), identify the invention to be searched by referring to the claims
   (see note (c))

5. Do you want any extra copies of any documents cited in the search report?
(see note (d))

   If so, state how many and remember to pay the extra fee

6. Signature JM Potter — Date 20-12-96

   DR J M POTTER
   Agent for the Applicant

7. Name and daytime telephone number of person to contact in the United Kingdom — James Seymour - 01276 419606

Fee Sheet (FS1)

(Deposit Account Holders)

The Patent Office

Account No. D02716

Name Nokia Mobile Phones (UK) Ltd

Address Patents Department
St Georges Court
St Georges Road

Camberley
UK
GU15 3QZ

Contact Paul Thomas

Tel No. 01276 419359 Date 9/12/96

Fax No. 01276 677720

Payment Method

a) Charge to Deposit Account X

b) Cheque enclosed for £

OR

c) Bank transfer of £

on (date)
(see Note 2)

Fee Sheet Reference (see Note 3) PAT 96035 GB

	Form Type (P / TM / D PCT / EP)	Form Number	Name, Number or Other Identifier	Amount of Fee £
1	P	1/77	Nokia Mobile Phones Ltd	25-00
2	P	9/77		130-00
3				
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Page 1 of 1 pages Total 155-00

Notes for guidance on the completion of this form are printed on the reverse

Method And Apparatus For Transmitting And Receiving Signals

The present invention relates to a method and apparatus for receiving a radio frequency signal, and a method and apparatus for transmitting a modulation signal.

Current mobile telephone systems are mainly provided by ground based (terrestrial) cellular systems such as GSM (Global System for Mobiles), PDC 800 or AMPS (American Mobile Phone System). Other mobile telephone systems include the Inmarsat-M satellite system, in which subscribers use briefcase-sized mobile telephones to make calls via geo-stationary orbiting satellites.

Several new proposals for mobile satellite telephone systems are currently under development by major telecommunications companies. These global systems have been well publicised and are known commercially by the trade names ICO, IRIDIUM, GLOBALSTAR and ODYSSEY. In parallel with the launch of these new mobile satellite systems, several terminal equipment manufacturers are developing handheld mobile units for use by subscribers of these systems. Some terminal equipment manufacturers are proposing developing dual-mode handsets which operate on both the ground based cellular systems and the new mobile satellite systems.

WO 96/08883 discloses a dual mode telephone device which is operable on both satellite and land based cellular communication systems. The device includes one set of antenna and radio frequency circuits for receiving and transmitting signals in a satellite network, and another set of antenna and radio frequency circuits for receiving and transmitting in a terrestrial network. A dual mode frequency synthesiser provides for wide channel spacings when supplying the terrestrial radio frequency circuits and narrow channel spacings when supplying the satellite radio frequency circuits.

According to a first aspect of the present invention there is provided a method of receiving a radio frequency signal in a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the method comprising the steps of: processing the radio frequency signal in combination with a first analogue demodulating signal to produce a first analogue intermediate signal, and processing the first analogue intermediate signal in combination with a second analogue demodulating signal to produce a second analogue intermediate signal, wherein the frequency resolution of the first analogue demodulating signal is wider than the channel spacing, and the frequency resolution of the second analogue demodulating signal is finer than the frequency resolution of the first analogue demodulating signal, and the frequencies of the first and second analogue demodulating signals are adjusted in accordance with their respective frequency resolutions in order to tune the receiver to the radio frequency signal.

Adjustment of the first and second demodulating signals may tune the receiver to the channel frequency of the radio frequency signal. Alternatively, adjustment of the first and second demodulating signals may tune the receiver to a channel frequency in the vicinity of the radio frequency signal in order for a digital tuning process to further tune the receiver to the channel frequency of the radio frequency signal.

According to a second aspect of the present invention there is provided a method for transmitting a modulation signal in a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the method comprising the steps of: processing the modulation signal in combination with a first analogue modulating signal to produce an analogue intermediate signal, and processing the analogue intermediate signal in combination with a second analogue modulating signal to produce a radio frequency output signal at a channel frequency of the multiple channel radio system, wherein the frequency

resolution of the second analogue modulating signal is wider than the channel spacing, and the frequency resolution of the first analogue modulating signal is finer than the frequency resolution of the second analogue modulating signal, and the frequencies of the first and second analogue modulating signals are adjusted in accordance with their respective frequency resolutions so as to change the channel frequency of the output signal.

The first or second analogue modulating or demodulating signal may vary across a range of frequencies in such a way that the possible frequency values which may be adopted by the signal have a minimum frequency separation. This minimum frequency separation is known as the frequency resolution of the signal and relates to the ability of the signal to resolve or differentiate between channel frequencies in the multiple channel radio system. The frequency resolution of the modulating or demodulating signal may be considered to be the minimum frequency jump that the modulating or demodulating signal may confidently perform. Accordingly, if the frequency resolution of a signal is widened then its ability to resolve is decreased i.e. the minimum jump that it may perform is larger. Conversely, if the frequency resolution of a signal is made finer then its ability to resolve is increased i.e. the minimum jump that it may perform is smaller.

A method in accordance with the first and/or second aspect of the invention provides an advantage that the aggregate settling time when changing channels in a transmitter or receiver may be decreased. By decreasing the settling time, a receiver or transmitter operating in accordance with the invention may be able to function within the specifications of newly proposed satellite telecommunications systems. Also, by decreasing the settling time, radio frequency circuits of the transmitter or receiver may be switched on slightly later. Consequently, the operating period of the radio frequency circuits may be reduced which in turn may reduce the power consumption in the transmitter or receiver.

In a preferred embodiment in accordance with the first aspect of the present invention, the first analogue intermediate signal is processed in combination with a further analogue demodulating signal before being processed in combination with the second analogue demodulating signal.

In a preferred embodiment in accordance with the second aspect of the present invention, the radio frequency output signal is processed in combination with a further modulating signal before being transmitted.

Preferably, the processing steps comprise mixing one signal in combination with another signal. The action of mixing one signal in combination with another signal is also referred to as frequency translation, frequency changing, or heterodyning.

Suitably, the modulating or demodulating signals are produced by frequency synthesisers. The frequency synthesisers may output a local oscillator signal which may be supplied to a mixing unit to enable the output to operate as a modulating or demodulating signal.

The first and second modulating or demodulating signals may be produced by separate frequency synthesisers.

One of the modulating or demodulating signals may be produced by a combined output of two frequency synthesisers.

In one preferred embodiment the frequency resolution of the second analogue demodulating signal or the first analogue modulating signal is equal to the channel spacing. Consequently, the second analogue demodulating signal or the first analogue modulating signal may select the individual channels in the multiple channel radio system.

In another preferred embodiment the frequency resolution of the second analogue demodulating signal or the first analogue modulating signal is greater than a channel spacing of the multiple channel radio system. In this case, selection of individual channels may be performed digitally in a base band environment.

According to a third aspect of the present invention there is provided radio frequency receiving apparatus for receiving a radio frequency signal of a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the apparatus comprising: signal generating means for producing a first analogue demodulating signal with a frequency resolution wider than the channel spacing, and a second analogue demodulating signal with a frequency resolution finer than the first analogue demodulating signal, first processing means for processing the radio frequency signal in combination with the first analogue demodulating signal to produce a first analogue intermediate signal, second processing means for processing the first analogue intermediate signal in combination with the second analogue demodulating signal to produce a second analogue intermediate signal, and adjusting means arranged in cooperation with the signal generating means to adjust the frequencies of the first and second demodulating signals in accordance with their respective frequency resolutions in order to tune the receiver to the radio frequency signal.

According to a fourth aspect of the present invention there is provided apparatus for transmitting a modulation signal in a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the apparatus comprising: signal generating means for producing a second analogue modulating signal with a frequency resolution wider than the channel spacing, and a first analogue modulating signal with a frequency resolution finer than the second analogue modulating signal, first processing means for processing the modulation signal in combination with the first analogue modulating signal to

produce an analogue intermediate frequency signal, second processing means for processing the analogue intermediate signal in combination with the second analogue modulating signal to produce a radio frequency output signal, and adjusting means arranged in cooperation with the signal generating means to adjust the frequencies of the first and second modulating signals within their respective frequency resolutions so as to change the channel frequency of the output signal.

In one embodiment the signal generating means comprises a first synthesiser for producing the first analogue modulating or demodulating signal, and a second synthesiser for producing the second analogue modulating or demodulating signal.

Ideally, the first and/or second processing means comprises a mixing unit. Signals input to the processing means may be mixed by the mixing unit with a modulating or demodulating signal.

According to a fifth aspect of the present invention there is provided a method for receiving a radio frequency signal of a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the method comprising the steps of: processing the radio frequency signal in combination with a first analogue demodulating signal to produce a first analogue intermediate signal, and processing the first analogue intermediate signal in combination with a second analogue demodulating signal to produce a second analogue intermediate signal, wherein the frequency resolution of the second analogue demodulating signal is wider than the channel spacing, and the frequency resolution of the first analogue demodulating signal is finer than the frequency resolution of the second analogue demodulating signal, and the frequencies of the first and second analogue demodulating signals are adjusted in accordance with their respective frequency resolutions in order to tune the receiver to the radio frequency signal.

According to a sixth aspect of the present invention there is provided a method for transmitting a modulation signal in a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the method comprising the steps of: processing the modulation signal in combination with a first analogue modulating signal to produce an analogue intermediate signal, and processing the analogue intermediate signal in combination with a second analogue modulating signal to produce a analogue radio frequency output signal, wherein the frequency resolution of the first analogue modulating signal is wider than the channel spacing, and the frequency resolution of the second analogue modulating signal is finer than the frequency resolution of the first analogue modulating signal, and the frequencies of the first and second analogue modulating signals are adjusted in accordance with their respective frequency resolutions so as to change the channel frequency of the output signal.

The apparatus or the method in accordance with the invention may be suitably incorporated in a mobile, transportable or handheld radio telephone.

Specific embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows a terrestrial mobile telecommunications system;

Figure 2 shows a satellite mobile telecommunications system;

Figure 3 shows a front view of a dual mode radio telephone;

Figure 4 shows a block diagram of the main functional components of the radio telephone shown in Figure 3.

Figure 5 shows a block diagram of a phase locked loop frequency synthesiser;

Figure 6 shows a block diagram of a radio frequency transceiver according to a first embodiment of the invention;

Figure 7 shows a block diagram of a radio frequency transceiver according to a second embodiment of the invention;

Figure 8 shows a block diagram of a radio frequency transceiver according to a third embodiment of the invention;

Figure 9 shows a block diagram of a radio frequency transceiver according to a fourth embodiment of the invention;

Figure 10 shows a schematic representation of satellite channels within the bandwidth of a 200 KHz intermediate frequency filter;

Figure 11 is a table showing frequency values for the SHF and VHF synthesisers of Figure 8 when receiving an IRIDIUM signal;

Figure 12 is a table showing frequency values for the SHF and VHF synthesisers of Figure 8 when transmitting an IRIDIUM signal;

Figure 13 is a table showing frequency values for the UHF and VHF synthesisers of Figure 9 when receiving an ICO signal; and

Figure 14 is a table showing frequency values for the UHF and VHF synthesisers of Figure 9 when transmitting an ICO signal.

In the terrestrial cellular telephone system shown in Figure 1, mobile handsets 101 and 102 communicate with the base stations 103, transferring data and digitised voice signals in a two way radio communication link. The base stations are linked together either directly or indirectly to form the cellular network, enabling telephone calls to be routed between handset 101 and handset 102. The terrestrial cellular network may also be linked to a landline telephone network 104, enabling telephone calls to be made between handsets 101 and 102 and landline telephones 106.

In the satellite telephone system shown in Figure 2, mobile handsets 101 and 102 communicate with the orbiting satellites 201 and 202, transferring data and digitised voice signals in a two way radio communication link. Data from several simultaneous calls is combined in a high bandwidth communication link between the satellites 201 and 202 and an Earth-bound satellite base station 203. In this way the satellites are indirectly linked together to form the satellite network. In another satellite telephone system the satellites communicate directly with one another using a satellite-to-satellite high bandwidth communication link. Like the terrestrial cellular networks, the Earth-bound satellite base station 203 may be linked to one or more landline telephone networks 104 and 105, enabling telephone calls to be made between handsets 101 and 102 and landline telephones 106.

A dual mode handset for use in a terrestrial telephone system or a satellite telephone system is shown in Figure 3. Several buttons 302 enable various operations to be performed, including accepting a call, terminating a call, dialling a number, storing a telephone number in an alphabetical index, and so on. An alphanumeric liquid crystal display 303 provides an indication of the telephone's status, including such information as signal strength, remaining battery power, the number which has been dialled, and so on. A microphone 304 converts sound pressure waves into an electrical signals, and a loudspeaker 305 converts electrical signals into sound pressure waves. Antennas 306 and 307 radiate electromagnetic waves at transmission frequencies during transmission, and during reception convert received electromagnetic waves at reception frequencies into electrical signals. In satellite mode the satellite antenna 307 is used to transmit and receive signals at frequencies used in satellite communication. In terrestrial mode the terrestrial antenna 306 is used to transmit and receive signals at frequencies used in terrestrial communication.

The main functional components of the dual mode mobile telephone 301 are shown in Figure 4. The microphone 304 generates analogue electrical signals

which are supplied to an analogue to digital converter 401. The analogue to digital converter 401 converts the analogue signals into a stream of binary numerical values representing instantaneous analogue voltages supplied by the microphone 304 at regular intervals.

Binary electrical signals representing the microphone sound pressure are supplied to a digital signal processor 402, which performs several base band processing functions on the sound signal before it is used to modulate a radio frequency signal. The digital signal processor 402 supplies a modulation signal to a radio frequency circuit 403. When transmitting, the output from the radio frequency circuit 403 is supplied to terrestrial antenna 306 or satellite antenna 307 depending on the operational mode of the telephone.

During reception, terrestrial antenna 306 or satellite antenna 307 supplies radio frequency signals to the radio frequency circuit 403. The radio frequency circuit supplies signals to the digital signal processor 402, for conversion into binary electrical samples representing sound. These binary electrical samples are supplied from the digital signal processor 402 to a digital to analogue converter 404, which converts these into an analogue voltage. The analogue voltage is supplied to the loudspeaker 305, for converting the analogue signal into sound.

A microcontroller 405 is connected to the liquid crystal display 303 and the buttons 302 shown in Figure 3. It is also connected to the digital signal processor 402, the radio frequency circuit 403, and other parts of the telephone circuit. Instructions executed by the microcontroller 405 co-ordinate circuit operations in response to user activation of the buttons 302, and signals provided by the circuit, such as battery strength and signalling information extracted by the digital signal processor 402.

In some systems the signal supplied by the digital signal processor 402 to the radio frequency circuit 403 may be purely a modulation signal, in other words it has a zero centre frequency and does not affect the centre frequency of the

channel on which the modulation signal is to be transmitted. Similarly, the signal supplied by the radio frequency circuit 403 to the digital signal processor 402 may be independent of the channel on which it has been received. In such a system, a radio frequency synthesiser in the radio frequency circuit is responsible for controlling the selection of channel frequencies.

Referring now to Figure 5A there is shown a radio frequency phase locked loop synthesiser. A radio frequency oscillator 501 contains a tuned circuit, having a resonant frequency defined by a varicap diode 502 and an inductor 503. The oscillator 501 is typically of the type known as a Hartley or Colpitts oscillator and a signal 504 is generated having a frequency F_{LO} defined by the resonant frequency of the tuned circuit.

The oscillator output 504 is supplied to a divider 505, which divides the oscillator frequency, F_{LO}, by an integer value, n. The divided frequency is supplied to a first input of a phase detector 506.

A reference oscillator 508 consists of a temperature-compensated crystal oscillator, having a quartz crystal 509. This oscillates at a fixed known frequency, which is divided by a fixed factor in the fixed divider 507. The output from the fixed divider 507 is known as the reference frequency, F_{REF}, and is supplied to a second input of the phase detector 506.

The phase detector generates an output voltage dependent on the difference in phase between its two inputs. This is supplied to a low pass loop filter 510, the output voltage 511 of which being dependent on the difference in phase between the two signals supplied to the phase detector 506. The output 511 from the loop filter 510 supplies a control voltage to the varicap diode 502 in the oscillator 501. The loop filter 510 generates a signal which pulls the phase and frequency F_{LO} of the oscillator 501 to a value, which after division by n in the variable divider 505, is equal to the phase and frequency of F_{REF}, from the fixed divider 507.

Thus a classic phase-locked loop is formed, with the frequency F_{LO} of the oscillator 501 being controlled by the integer, n, used in divider 505, and the channel spacing between increments of n being defined by the value of F_{REF}.

Unfortunately the programmable divider 505 cannot operate at input frequencies of greater than a few tens of megahertz, without raising cost and power consumption to unacceptable levels. A possible solution is to pre-divide the signal 504 by some fixed value using a fixed high speed divider. This technique is known as prescaling. This creates an additional problem in that F_{REF} must be divided by the same amount, since the channel spacing is now equal to F_{REF} multiplied by the prescaling factor.

The problem with the arrangement in Figure 5A is further explained in Figure 5B. Without extreme filtering, due to radio frequency feed-through, sidebands 521 and 522 are imposed on the output 504 from oscillator 501, which has a centre frequency 520. These sidebands will degrade or distort reception of the desired channel by adding unwanted modulation components. Furthermore, selectivity of adjacent reception channels will be reduced. A lower cut-off frequency could be used for the loop filter 510, in order to reduce the amplitudes of the sidebands 521 and 522, but this would result in an increase in the loop settling time. Thus narrow channel spacing and fast settling time are contradictory requirements.

Mobile radio transmission is subject to variations in signal strength due to reflections from obstacles such as buildings, trees and cars. The same radio signal may be received from several reflecting surfaces, resulting in constructive and destructive interference. The consequent changes in signal amplitude are known as Rayleigh fading. At any given moment in time, it is possible for some frequency channels to be rendered unusable by destructive interference.

The concept of frequency diversity is key to the solution of this and other interference problems in mobile radio systems. In the GSM, ICO and IRIDIUM

specifications for digital cellular phones, frequency hopping is used, in which each reception or transmission burst may operate at a different frequency. Voice data is encoded in a redundant interleaved format, thus, if a particular frequency suffers interference, the missing data can be, at least partially, reconstructed from previous and subsequent bursts without communication being interrupted.

The implementation of frequency hopping imposes certain requirements on the frequency synthesiser used for selecting the desired channels. The synthesiser must be capable of switching to new frequencies within time constraints set down by the particular network protocol. The time taken for the synthesiser to settle to a new frequency is known as the settle time.

The characteristics of the radio frequency phase locked loop are the determining factor for the settling time of a radio frequency synthesiser. Referring back to Figure 5 a problem with the phase locked loop is feed-through of the F_{REF} signal from the fixed divider 507, through the phase detector 506, to the signal 511 supplied to the oscillator 501. An effect of this feed-through is instability in the phase locked loop. Removal of F_{REF} from the output of the phase detector 506, and hence any instability in the phase locked loop, is performed by the loop filter 510. However, as the loop filter 510 is a low pass filter its effect is to dampen changes or hops in the frequency F_{LO} which occur as a result of changes in integer n. In general, the settle time of the phase locked loop is inversely proportional to the loop filter cut-off frequency, i.e. the lower the cut-off frequency of the low pass filter, the longer the settle time of the phase locked loop. Also, the settle time of the phase locked loop is, in general, proportional to the magnitude of the change in frequency F_{LO}, i.e. the greater the change in frequency F_{LO}, the longer the settle time of the phase locked loop.

In the GSM recommendations, frequency hopping is performed on reception channels spaced 200 KHz apart and with a maximum frequency hop of 25 MHz. The GSM specification also requires that a receiver is capable of performing a single frequency hop within 0.8 ms. This requires a radio frequency synthesiser

to settle to its new frequency in less than 0.8 ms. The GSM standard was developed with an awareness of the practical difficulties associated with frequency hopping and the specification is sufficiently undemanding to allow known frequency synthesisers which achieve sufficiently short settle times to be used.

In the proposed standards for satellite telephone systems, such as ICO, the switch times for fast frequency hopping have to be as short as 0.5 ms. In ICO this is partly due to dynamic allocation of RX and TX slots. Such a switch time would be possible in known frequency synthesisers if the channel spacing was comparable with the 200 KHz channel spacing found in GSM. Unfortunately, a particular constraint on the ICO satellite-based telephone system currently under development is the further requirement for a narrow channel spacing of 25 KHz, in order to make viable economic exploitation of the available bandwidth. Using the phase locked loop synthesiser of Figure 5, the value of F_{REF} would have to be 25 KHz or less to enable the selection of all possible channels in the ICO satellite receive or transmit bands. Accordingly, to prevent the 25 KHz F_{REF} signal destabilising the phase locked loop, a much lower cut-off frequency would have to be used in the loop filter 510 when compared to the cut-off frequency required in the GSM system. A result of this would be long settling times, which directly conflict with proposals for the ICO satellite system. Consequently, the phase locked loop synthesiser of Figure 5 would not be able to manage the fast frequency hops required by the proposed ICO satellite system, particularly for frequency hops tending towards the maximum jump of 30 MHz in the ICO transmit and receive bands.

Even for mobile telephone systems that do not insist on fast settling times, unnecessary lengthening of the settling times in the transceiver results in the frequency synthesisers being switched on for a longer period than is necessary. Therefore, any measures taken to reduce the settling time of the transceiver will help to save power in the transceiver as a result of the frequency synthesisers

being switched off for longer. By saving power in the transceiver, talk times and standby times may advantageously be increased.

The dual mode radio telephone of Figure 4, in particular the radio frequency circuit 403, will be described in more detail with reference to four embodiments illustrated in Figures 6 to 9.

The four specific embodiments of the invention described hereafter each include a front-end RF stage specifically for receiving satellite signals transmitted from an ICO or IRIDIUM network, and a front-end RF stage specifically for receiving terrestrial signals transmitted from a GSM network. For transmission, the four embodiments each include a terminal RF stage specifically for transmitting satellite signals suitable for reception by an ICO or IRIDIUM network, and a terminal RF stage specifically for transmitting terrestrial signals suitable for reception by a GSM network. In addition, the four embodiments each include two common RF stages, one for reception and one transmission, which are used by the transceiver in both satellite mode and terrestrial mode. In other words, the common RF stage for reception is shared by the satellite and terrestrial receive paths, and the common RF stage for transmission is shared by the satellite and terrestrial transmit paths.

Figure 6 illustrates a first embodiment of the invention designed for use in the terrestrial GSM system and the satellite IRIDIUM system. Referring to receive operation of the radio frequency circuit in GSM mode, a terrestrial antenna 306a of the GSM front-end RF stage receives a signal within the GSM reception band of 935 to 960 MHz and supplies the received signal to a mixer 601 via a GSM bandpass filter 602. By mixing the received signal with a local oscillator signal having a frequency in the frequency range 1006 to 1031 MHz, a desired channel in the received signal is converted to a first intermediate frequency of 71 MHz. The selection of frequencies for the local oscillator signal is controlled by the output of a UHF synthesiser 603 which, under the control of the microcontroller 405 (see Figure 4), provides an output signal in the frequency range 1470 to

1495 MHz in 200 KHz steps. The output signal of the UHF synthesiser is converted down to the frequency range 1006 to 1031 MHz by a mixer 604 in combination with a 464 MHz local oscillator signal. The 464 MHz signal is provided by a multiplier 606 coupled to a VHF signal generator 605 operating at 232 MHz. The resultant first intermediate frequency signal passes through a mode switch 607 which in GSM mode is switched to the GSM front-end RF stage as shown in Figure 6. A second mixer 608, supplied with a local oscillator signal of 58 MHz, converts the first intermediate frequency signal down to a second intermediate frequency of 13 MHz. The 58 MHz signal is provided by a divider 609 fed with a 232 MHz signal from a VHF signal generator 605. The resultant second intermediate frequency signal is then fed into the base band section of the radio telephone for subsequent decoding.

Referring to the transmit operation of the radio frequency circuit in GSM mode, a pure modulation signal, intended for transmission in the GSM transmission band, is supplied from the base band section to a mixer 610. The modulation signal is mixed with a 116 MHz signal provided by a divider 611 coupled to the VHF signal generator 605 operating at 232 MHz. The resultant intermediate frequency signal at 116 MHz passes through a mode switch 612, which in GSM mode is switched to the GSM terminal RF stage, and is fed into a second mixer 613. By mixing the intermediate frequency signal with a local oscillator signal having a frequency in the frequency range 1006 to 1031 MHz, the intermediate frequency signal is converted to a transmit channel frequency of the GSM transmission band. The selection of frequencies for the local oscillator signal is controlled by the output of the UHF synthesiser 603 which, under the control of the microcontroller 405, provides an output signal in the frequency range 1470 to 1495 MHz in 200 KHz steps. The output signal of the UHF synthesiser 603 is converted down to the frequency range 1006 to 1031 MHz by the mixer 604 in combination with the 464 MHz local oscillator signal. Selection of a particular transmit channel in the GSM transmission band of 890 to 915 MHz is achieved by the microcontroller 405 selecting an appropriate frequency for the output

signal of the UHF synthesiser 603. The transmit signal output from the mixer 613 is supplied to the terrestrial antenna 306b via the GSM bandpass filter 614.

Referring to the receive operation of the radio frequency circuit in IRIDIUM satellite mode, a satellite antenna 307a of the IRIDIUM front-end RF stage receives a signal within the IRIDIUM reception band of 1616 to 1626 MHz and supplies the received signal to a mixer 616 via an IRIDIUM bandpass filter 615. By mixing the received signal with a local oscillator signal having a frequency in the frequency range 1545 to 1555 MHz, a desired channel in the received signal is converted to a first intermediate frequency of 71 MHz. The selection of frequencies for the local oscillator signal is controlled by the output of a UHF synthesiser 603 which, under the control of the microcontroller 405, provides an output signal in the frequency range 1545 to 1555 MHz in 41.67 KHz steps. The resultant first intermediate frequency signal passes through the mode switch 607 which in IRIDIUM mode is switched to the IRIDIUM front-end RF stage as indicated by the dashed line in Figure 6. The mixer 608, supplied with the local oscillator signal of 58 MHz, converts the first intermediate frequency signal down to a second intermediate frequency of 13 MHz. The resultant second intermediate frequency signal is then fed into the base band section of the radio telephone for subsequent decoding.

Referring to the transmit operation of the radio frequency circuit in IRIDIUM mode, a pure modulation signal, intended for transmission in the IRIDIUM transmission band, is supplied from the base band section to a mixer 610. The modulation signal is mixed with the 116 MHz signal. The resultant intermediate frequency signal at 116 MHz passes through the mode switch 612, which in IRIDIUM mode is switched to the IRIDIUM terminal RF stage, and is fed into a second mixer 617. By mixing the intermediate frequency signal with a local oscillator signal having a frequency in the range 1500 to 1510 MHz, the intermediate frequency signal is converted to a transmit channel frequency of the IRIDIUM transmission band. The selection of frequencies for the local oscillator signal is controlled by the output of the UHF synthesiser 603 which,

under the control of the microcontroller 405, provides an output signal in the frequency range 1500 to 1510 MHz in 41.67 KHz steps. Selection of a particular transmit channel in the IRIDIUM transmission band of 1616 to 1626 MHz is therefore achieved by the microcontroller 405 selecting an appropriate frequency for the output signal of the UHF synthesiser 603. The transmit signal output from the mixer 617 is supplied to the satellite antenna 307b via the IRIDIUM bandpass filter 618.

Thus for the first embodiment shown in Figure 6 the front-end RF stage for receiving GSM terrestrial signals comprises the terrestrial antenna 306a, the GSM bandpass filter 602, and the mixer 601. Likewise, the front-end RF stage for receiving IRIDIUM satellite signals comprises the satellite antenna 307a, the IRIDIUM bandpass filter 615, and the mixer 616. The common RF stage for reception comprises the switch 607, for selectively receiving either the output of the mixer 601 or the mixer 616, and the mixer 608. The common RF stage for transmission comprises the mixer 610, and the switch 612, for providing the intermediate frequency signal to either the terrestrial or the satellite terminal RF stage. The terminal RF stage for transmitting GSM terrestrial signals comprises the mixer 613, the GSM bandpass filter 614, and the terrestrial antenna 306b. The terminal RF stage for transmitting IRIDIUM satellite signals comprises the mixer 617, the IRIDIUM bandpass filter 618, and the satellite antenna 307b.

Figure 7 illustrates a second embodiment of the invention designed for use in the terrestrial GSM system and the satellite ICO system. Referring to receive operation of the radio frequency circuit in GSM mode, a terrestrial antenna 306a of the GSM front-end RF stage receives a signal within the GSM reception band of 935 MHz to 960 MHz. The received signal then continues via a mode switch 707 and a GSM bandpass filter 702 onto a mixer 701. By mixing the received signal with a local oscillator signal having a frequency in the frequency range 1006 to 1031 MHz, a desired channel in the received signal is converted to a first intermediate frequency of 71 MHz. The selection of frequencies for the local oscillator signal is controlled by the output of a UHF synthesiser 703 which,

under the control of the microcontroller 405, provides an output signal in the frequency range 1006 to 1031 MHz in 200 KHz steps. A second mixer 708, supplied with a local oscillator signal of 58 MHz, converts the first intermediate frequency signal down to a second intermediate frequency of 13 MHz. The 58 MHz signal is provided by a divider 709 fed with a 232 MHz signal from a VHF signal generator 705. The resultant second intermediate frequency signal is then fed into the base band section of the radio telephone for subsequent decoding.

Referring to the transmit operation of the radio frequency circuit in GSM mode, a pure modulation signal, intended for transmission in the GSM transmission band, is supplied from the base band section to a mixer 710. The modulation signal is mixed with a 116 MHz signal provided by a divider 711 coupled to the VHF signal generator 705 operating at 232 MHz. The resultant intermediate frequency signal at 116 MHz is fed into a second mixer 713. By mixing the intermediate frequency signal with a local oscillator signal having a frequency in the frequency range 1006 to 1031 MHz, the signal is converted to a transmit channel frequency of the GSM transmission band. The selection of frequencies for the local oscillator signal is controlled by the output of the UHF synthesiser 703 which, under the control of the microcontroller 405, provides an output signal in the frequency range 1006 to 1031 MHz in 200 KHz steps. Selection of a particular transmit channel in the GSM transmission band of 890 to 915 MHz is therefore achieved by the microcontroller selecting an appropriate frequency for the output signal of the UHF synthesiser. The transmit signal output from the mixer 613 continues via a GSM bandpass filter 714 and a mode switch 712 onto the terrestrial antenna 306b.

Referring to the receive operation of the radio frequency circuit in ICO satellite mode, a satellite antenna 307a of the ICO front-end RF stage receives a signal within the ICO reception band of 2170 to 2200 MHz and supplies the received signal to a mixer 716 via an ICO bandpass filter 715. By mixing the received signal with a local oscillator signal having an appropriate frequency a desired channel in the received signal is converted to a first intermediate frequency of

940 MHz. The local oscillator signal is produced by the output of a SHF synthesiser 719 which, under the control of the microcontroller 405, provides an output signal in the frequency range 1230 to 1260 MHz in 25 KHz steps. The resultant first intermediate frequency signal passes through the mode switch 707 which in ICO mode is switched to the ICO front-end RF stage as indicated by the dashed line in Figure 7. After passing through the GSM band filter 702 the received ICO signal is fed into the mixer 701. The mixer 701, supplied with a constant local oscillator signal of 1011 MHz from the UHF synthesiser 703, converts the first intermediate frequency signal down to a second intermediate frequency of 71 MHz. A third mixer 708 supplied with a 58 MHz local oscillator signal converts the second intermediate frequency signal down to a third intermediate frequency of 13 MHz. The resultant third intermediate frequency signal is then fed into the base band section of the radio telephone for subsequent decoding.

Referring to the transmit operation of the radio frequency circuit in ICO mode, a pure modulation signal, intended for transmission in the ICO transmission band, is supplied from the base band section to a mixer 710. The modulation signal is mixed with the 116 MHz signal. The resultant intermediate frequency signal at 116 MHz is supplied to a second mixer 713 which in combination with a 1011 MHz signal from the UHF synthesiser produces a second intermediate frequency signal at 895 MHz. The second intermediate frequency signal continues via GSM bandpass filter 714 and a mode switch 712, which in ICO mode is switched to the ICO terminal RF stage, and is fed into a second mixer 717. By mixing the second intermediate frequency signal with a local oscillator signal having a frequency in the range 1085 to 1115 MHz, the intermediate frequency signal is converted to a transmit channel frequency of the ICO transmission band. The selection of frequencies for the local oscillator signal is controlled by the output of the SHF synthesiser 719 which, under the control of a microcontroller, provides an output signal in the frequency range 1230 to 1260 MHz in 25 KHz steps. Using a 145 MHz local oscillator signal from signal generator 702, mixer unit 721 converts the output of the SHF synthesiser 719 to the frequency range

1085 to 1115 MHz. The transmit signal output from the mixer 717 is supplied to the satellite antenna 307b via an ICO bandpass filter 718.

Thus for the second embodiment shown in figure 7 the front-end RF stage for receiving GSM terrestrial signals comprises the terrestrial antenna 306a. The front-end RF stage for receiving ICO satellite signals comprises the satellite antenna 307a, the ICO bandpass filter 715, and the mixer 716. The common RF stage for reception comprises the switch 707, for selectively receiving either the output of the terrestrial antenna 306a or the mixer 716, the GSM bandpass filter 702, and the mixers 701 and 708. The common RF stage for transmission comprises the mixers 710 and 713, the GSM bandpass filter 714, and the switch 712, for providing the intermediate frequency signal to either the terrestrial or the satellite terminal RF stage. The terminal RF stage for transmitting GSM terrestrial signals comprises the terrestrial antenna 306b. The terminal RF stage for transmitting ICO satellite signals comprises the mixer 717, the ICO bandpass filter 718, and the satellite antenna 307b.

As discussed previously with reference to Figure 5, the standard type of phase locked loop synthesiser is not able to provide both fast frequency hopping and narrow channel spacings. This is a particular problem for the proposed ICO satellite network and may also prove a problem in other proposed satellite networks such as IRIDIUM, GLOBALSTAR and ODYSSEY. Therefore, in order to overcome the drawbacks of the standard phase locked loop the UHF frequency synthesiser 603 and the SHF frequency synthesiser 719 comprise an improved phase locked loop known as a fractional n phase locked loop. In contrast to the standard phase locked loop where the divider 505 divides the signal F_{LO} by an integer n, the fractional n phase locked loop is able to divide the signal at the same divider stage by any real positive number. The fractional n phase locked loop is thus able to provide channel spacings determined by the product of the F_{REF} frequency and the fractional increments of n. The channel spacings are no longer decided purely by the frequency of F_{REF}, and hence a improved settling time for the ICO or IRIDIUM systems may be realised by selecting an appropriate

frequency for F_{REF} in the UHF synthesiser 603 or in the SHF synthesiser 719. The resolution of n is then determined according to the frequency of F_{REF} and the channel spacings in the IRIDIUM or ICO systems.

The power consumption of a transceiver is dependent on the operational time of the transceiver circuitry. Long settling times result in increased operational time of the transceiver circuitry and hence increased power consumption. Therefore, by decrease the settling times of the transceiver the fractional n synthesiser may provide the added benefit of decreased power consumption in the IRIDIUM or ICO transceiver.

The UHF synthesiser 603 and the SHF synthesiser 719 includes a fractional n phase locked loop in which the frequency of the F_{REF} signal is 200 KHz. At this frequency the loop filter cut off is sufficiently high to enable frequency hopping to occur within the 0.5 ms required by the ICO specifications even for the largest hop of 30 MHz in the ICO receive and transmit bands. By varying the value of n with a resolution of 1/8, the UHF synthesiser 719 is able to jump in suitable frequency increments of 25 KHz required during the reception or transmission of ICO signals. By varying the value of n with a resolution of 1/24, the SHF synthesiser 603 is able to jump in suitable frequency increments of 41.67 KHz required during the reception or transmission of IRIDIUM signals

The GSM, IRIDIUM and ICO transmit and receive paths, which correspond to the respective transmit and receive operations of the radio frequency circuits of Figures 6 and 7, may be provided with signal amplification stages and intermediate frequency bandpass filter stages for improving the transmit and receive signals. For example, the received GSM signal in Figure 6 and 7 may be amplified after passing through the GSM bandpass filter 602 or 702 prior to supplying the mixing unit 601 or 701. Similarly, the transmit GSM signal may be amplified after the mixing unit 613 or 713 prior to being transmitted by the terrestrial antenna 306b. Also, the received IRIDIUM and ICO signal in Figure 6 and Figure 7 may be amplified after passing through the IRIDIUM bandpass filter

615 or ICO bandpass filter 715 prior to supplying the mixing unit 616 or 716. Similarly the transmit IRIDIUM or ICO signal may be amplified after the mixing unit 617 or 717 prior to being transmitted by the satellite antenna 307b.

Intermediate frequency bandpass filters may be provided at the 71 MHz and 13 MHz intermediate frequency stages during reception, and at the 116 MHz intermediate frequency stage during transmission to provide added selectivity and to reject interference from adjacent channels. These intermediate frequency bandpass filters may have a bandwidth of 200 KHz, equal to the channel bandwidth in the GSM system. In this way the intermediate frequency bandpass filters can provide single channel selectivity for the GSM signals, having a channel bandwidth of 200 KHz, and still permit the passage of IRIDIUM and ICO signals, having a channel bandwidth of 41.67 and 25 KHz respectively. The operation of the intermediate frequency bandpass filter in relation to the ICO satellite channels is illustrated schematically in Figure 10. The dotted line shows the bandpass filter centred on the intermediate frequency F and having a total bandwidth of 200 KHz. The desired ICO satellite channel is shown as a solid line centred on the intermediate frequency F and having a total channel bandwidth of 25 KHz. Six other neighbouring satellite channels are shown at the positions -3, -2, -1, +1, +2, and +3. All seven of the satellite channels shown in Figure 10 can proceed through the intermediate frequency bandpass filter. Therefore, during reception further digital filtering of the received IRIDIUM and ICO signals may be performed in base band to achieve added selectivity of the desired satellite channel not provided for by the 200 KHz intermediate frequency bandpass filters.

Figure 8 illustrates a third embodiment of the invention designed for use in the terrestrial GSM system and the satellite IRIDIUM system. Referring to receive operation of the radio frequency circuit in GSM mode, a terrestrial antenna 306a of the GSM front-end RF stage receives a signal within the GSM reception band of 935 MHz to 960 MHz and supplies the received signal to a mixer 801 via a GSM bandpass filter 802. By mixing the received signal with a local oscillator

signal having a frequency in the frequency range 1006 to 1031 MHz, a desired channel in the received signal is converted to a first intermediate frequency of 71 MHz. The selection of frequencies for the local oscillator signal is controlled by the output F_{LO} of a UHF synthesiser 803 which, under the control of a microcontroller, provides an output signal in the frequency range 1006 to 1031 MHz in 200 KHz steps. The resultant first intermediate frequency signal passes through a mode switch 807 which in GSM mode is switched to the GSM front-end RF stage as shown in Figure 8. A second mixer 808, supplied with a local oscillator signal of 58 MHz, converts the first intermediate frequency signal down to a second intermediate frequency of 13 MHz. The 58 MHz signal is provided by a divider 809 fed with a 232 MHz signal from a VHF synthesiser 805. The resultant second intermediate frequency signal is then fed into the base band section of the radio telephone for subsequent decoding.

Referring to the transmit operation of the radio frequency circuit in GSM mode, a pure modulation signal, intended for transmission in the GSM transmission band, is supplied from the base band section to a mixer 810. The modulation signal is mixed with a 116 MHz signal provided by a divider 811 coupled to the VHF signal generator 805 operating at 232 MHz. The resultant intermediate frequency signal at 116 MHz passes through a mode switch 812, which in GSM mode is switched to the GSM terminal RF stage, and is fed into a second mixer 813. By mixing the intermediate frequency signal with a local oscillator signal having a frequency in the frequency range 1006 to 1031 MHz, the intermediate frequency signal is converted to a transmit channel frequency of the GSM transmission band. The selection of frequencies for the local oscillator signal is controlled by the output of the UHF synthesiser 803 which, under the control of a microcontroller, provides an output signal in the frequency range 1006 to 1031 MHz in 200 KHz steps. Selection of a particular transmit channel in the GSM transmission band of 890 to 915 MHz is therefore achieved by the microcontroller selecting an appropriate frequency for the output signal of the UHF synthesiser 803. The output of the mixer 813 is supplied to the terrestrial antenna 306b via the GSM bandpass filter 814.

Referring to the receive operation of the radio frequency circuit in IRIDIUM satellite mode, a satellite antenna 307a of the IRIDIUM front-end RF stage receives a signal within the IRIDIUM reception band of 1616 to 1626 MHz and supplies the received signal to a mixer 816 via an IRIDIUM bandpass filter 815. By mixing the received signal with a local oscillator signal having a frequency in the frequency range 1545 to 1555 MHz, a desired channel in the intermediate frequency signal is converted to a first intermediate frequency in the range 70.5 to 71.5 MHz. The selection of frequencies for the local oscillator signal is controlled by the output F_{LO} of a SHF synthesiser 819 which, under the control of a microcontroller, provides an output signal in the frequency range 1545 to 1555 MHz in 1000 KHz steps. The resultant first intermediate frequency signal passes through the mode switch 807 which in IRIDIUM mode is switched to the IRIDIUM front-end RF stage as indicated by the dashed line in Figure 8. A second mixer 808, supplied with an appropriate local oscillator signal in the range 57.5 to 58.5 MHz, converts the first intermediate frequency signal in the range 70.5 to 71.5 MHz down to a second intermediate frequency of 13 MHz. The VHF synthesiser 805 provides a tuning local oscillator signal in the range 230.0 to 234.0 in 166.67 KHz steps which when coupled to the divider 809 provides a tuning local oscillator signal in the range 57.5 to 58.5 MHz in 41.67 KHz steps. The resultant 13 MHz second intermediate frequency signal is then fed into the base band section of the radio telephone for subsequent decoding.

Referring to the transmit operation of the radio frequency circuit in IRIDIUM mode, a pure modulation signal, intended for transmission in the IRIDIUM transmission band, is supplied from the base band section to a mixer 810. The modulation signal is mixed with a tuning local oscillator signal in the range 115.5 to 116.5 MHz in 41.67 KHz steps provided by a divider coupled to the VHF signal generator 805 operating in the range 231.0 to 233.0 in 83.33 KHz steps via a divider 811 to the mixer 810. The resultant intermediate frequency signal in the range 115.5 to 116.5 MHz passes through a mode switch 812, which in IRIDIUM mode is switched to the IRIDIUM terminal RF stage, and is fed into a

second mixer 815. By mixing the intermediate frequency signal with a tuning local oscillator signal having a frequency in the range 1500 to 1510 MHz, the intermediate frequency signal is converted to a transmit channel frequency of the IRIDIUM transmission band. The selection of frequencies for the local oscillator signal is controlled by the output F_{LO} of the SHF synthesiser 819 which, under the control of a microcontroller, provides an output signal in the frequency range 1500 to 1510 MHz in 1000 KHz steps. Selection of a particular transmit channel in the IRIDIUM transmission band of 1616 to 1626 MHz is therefore achieved by the microcontroller selecting an appropriate frequencies for the SHF and VHF synthesisers. The transmit signal output from the mixer 817 is supplied to the satellite antenna 307b via the IRIDIUM bandpass filter 818.

Thus for the third embodiment shown in Figure 8 the front-end RF stages, the terminal RF stages, and the common RF stages are equivalent to those shown in Figure 6.

The problem of achieving fast frequency hopping and fine channel resolution is solved in the third embodiment by using more than one tuneable synthesiser to receive and transmit the satellite signals.

In the third embodiment the SHF synthesiser 819 provides coarse tuning across the IRIDIUM transmit and receive bands and includes a standard phase locked loop in which a 200 KHz F_{REF} signal is supplied to the phase detector 506. With the F_{REF} signal operating at 200 KHz, the loop filter cut-off is high, resulting in a decrease in the settling time of the synthesiser which in turn can save power in the transceiver. In contrast, the VHF synthesiser 805 provides fine tuning across a relatively narrow range to achieve the precise channel selection required during the reception or transmission of IRIDIUM signals.

Figure 11 presents suitable values for the SHF synthesiser 819 and VHF synthesiser 805 when receiving IRIDIUM satellite signals from channels 8 to 23. Similarly, Figure 12 presents suitable values for the SHF synthesiser 819 and

VHF synthesiser 805 in Figure 8 when transmitting IRIDIUM satellite signals from channels 8 to 23. The SHF synthesiser 819 varies across the full 10 MHz bandwidth associated with the IRIDIUM transmit and receive bands, whereas the VHF synthesiser 805 varies across a relatively narrower frequency range centred around 232 MHz. As such, the VHF synthesiser 805 tunes in finer steps of 166.67 KHz during reception and 83.33 KHz during transmission and because the maximum frequency jump of the VHF synthesiser when hopping between channels is relatively small, the VHF synthesiser does not significantly increase the settling time of the transmitter or receiver.

The GSM and IRIDIUM transmit and receive paths, which correspond to the respective transmit and receive operations of the radio frequency circuit of Figures 8, may be provided with signal amplification stages and an intermediate frequency bandpass filter stage for improving the respective transmit or receive signals. For example, the received GSM signal in Figure 8 may be amplified after passing through the GSM bandpass filters 802 prior to supplying the mixing unit 801. Similarly, the transmit GSM signal may be amplified after the mixing unit 813 prior to being transmitted by the terrestrial antenna 306b. Also, the received IRIDIUM signal in Figure 8 may be amplified after passing through the IRIDIUM bandpass filter 815 prior to supplying the mixing unit 816. Similarly the transmit IRIDIUM signal may be amplified after the mixing unit 817 prior to being transmitted by the satellite antenna 307b.

An intermediate frequency bandpass filter may be provided at the 13 MHz intermediate frequency stage during reception to provide added selectivity and to reject interference from adjacent channels. This intermediate frequency bandpass filter may have a bandwidth of 200 KHz, equal to the channel bandwidth in the GSM system. In this way the intermediate frequency bandpass filter can provide the single channel selectivity for the GSM signals having a channel bandwidth of 200 KHz and still permit the passage of IRIDIUM signals having a channel bandwidth of 41.67 KHz.

Figure 9 illustrates a fourth embodiment of the invention designed for use in the terrestrial GSM system and the satellite ICO system. Referring to receive operation of the radio frequency circuit in GSM mode, a terrestrial antenna 306a of the GSM front-end RF stage receives a signal within the GSM reception band of 935 MHz to 960 MHz. The received signal then continues via a mode switch 907 and a GSM bandpass filter 902 onto a mixer 901. By mixing the received signal with a local oscillator signal having a frequency in the frequency range 1006 to 1031 MHz, a desired channel in the received signal is converted to a first intermediate frequency of 71 MHz. A mixer 920, supplied with a fixed 232 MHz signal from the VHF synthesiser 905 and a variable frequency signal from the UHF synthesiser 903, provides the local oscillator signal. The selection of frequencies for the local oscillator signal is controlled by the output of a UHF synthesiser 903 which, under the control of a microcontroller, provides an output signal in the frequency range 1238.0 to 1263.0 MHz in 200 KHz steps. A second mixer 908, supplied with a local oscillator signal of 58 MHz, converts the first intermediate frequency signal down to a second intermediate frequency of 13 MHz. The 58 MHz signal is provided by a divider 909 fed with a 232 MHz signal from a VHF signal generator 905. The resultant second intermediate frequency signal is then fed into the base band section of the radio telephone for subsequent decoding.

Referring to the transmit operation of the radio frequency circuit in GSM mode, a pure modulation signal, intended for transmission in the GSM transmission band, is supplied from the base band section to a mixer 910. The modulation signal is mixed with a 116 MHz signal provided by a divider 911 coupled to the VHF signal generator 905 operating at 232 MHz. The resultant intermediate frequency signal at 116 MHz is fed into a second mixer 913. By mixing the intermediate frequency signal with a local oscillator signal having a frequency in the frequency range 1006 to 1031 MHz, the signal is converted to a transmit channel frequency of the GSM transmission band. A mixer 920, supplied with a fixed 232 MHz signal from the VHF synthesiser 905 and a variable frequency signal from the UHF synthesiser 903, provides the local oscillator signal. The

selection of frequencies for the local oscillator signal is controlled by the output of the UHF synthesiser 903 which, under the control of the microcontroller 405, provides an output signal in the frequency range 1238.0 to 1263.0 MHz in 200 KHz steps. Selection of a particular transmit channel in the GSM transmission band of 890 to 915 MHz is therefore achieved by the microcontroller selecting an appropriate frequency for the output signal of the UHF synthesiser 903. The transmit signal output from the mixer 913 continues via a GSM bandpass filter 914 and a mode switch 912 onto the terrestrial antenna 306b.

Referring to the receive operation of the radio frequency circuit in ICO satellite mode, a satellite antenna 307a of the ICO front-end RF stage receives a signal within the ICO reception band of 2170 to 2200 MHz and supplies the received signal to a mixer 916 via an ICO bandpass filter 915. By mixing the received signal with a local oscillator signal having an appropriate frequency a desired channel in the received signal is converted to a first intermediate frequency in the range 933.4 to 948.6 MHz. The local oscillator signal is produced by the output F_{LO} of the UHF synthesiser 903 which, under the control of a microcontroller, provides an output signal in the frequency range 1236.6 to 1251.6 MHz in 200 KHz steps. The resultant first intermediate frequency signal passes through the mode switch 907 which in ICO mode is switched to the ICO front-end RF stage as indicated by the dashed line in Figure 9. After passing through the GSM band filter 902 the received ICO signal is fed into the mixer 901. The mixer 901, supplied with a constant local oscillator signal of 1011 MHz from the UHF synthesiser 903 and the VHF synthesiser 905, converts the first intermediate frequency signal down to a second intermediate frequency of 71 MHz. A third mixer 908 supplied with a 58 MHz local oscillator signal converts the second intermediate frequency signal down to a third intermediate frequency of 13 MHz. The resultant third intermediate frequency signal is then fed into the base band section of the radio telephone for subsequent decoding.

Referring to the transmit operation of the radio frequency circuit in ICO mode, a pure modulation signal, intended for transmission in the ICO transmission band,

is supplied from the base band section to a mixer 910. The modulation signal is mixed with a 116 MHz signal provided by a divider 911 coupled to the VHF signal generator 905 operating at 232 MHz. The resultant intermediate frequency signal at 116 MHz is supplied to a second mixer 913 which in combination with a 1011 MHz signal from the UHF synthesiser produces a second intermediate frequency signal at 895 MHz. The second intermediate frequency signal continues via the GSM bandpass filter 914 and a mode switch 912, which in ICO mode is switched to the ICO terminal RF stage, and is fed into a second mixer 917. By mixing the second intermediate frequency signal with a local oscillator signal having a frequency of 1090 MHz, the intermediate signal is converted to a transmit channel frequency of the ICO transmission band. The transmit signal output from the mixer 917 is supplied to the satellite antenna 307b via the ICO bandpass filter 918.

Thus for the fourth embodiment shown in Figure 9 the front-end RF stages, the terminal RF stages, and the common RF stages are equivalent to those shown in Figure 7.

The problem of achieving fast frequency hopping and fine channel resolution is solved in the fourth embodiment by using more than one tuneable synthesiser to receive and transmit the satellite signals.

In the fourth embodiment the UHF synthesiser 903 provides coarse tuning across the ICO transmit and receive bands and includes a standard phase locked loop in which a 200 KHz F_{REF} signal is supplied to the phase detector 506. With the F_{REF} signal operating at 200 KHz, the loop filter cut-off is sufficiently high to enable frequency hopping to occur within the 0.5 ms required by the ICO specifications even for the largest frequency hop of 30 MHz in the ICO receive and transmit bands. In contrast, the VHF synthesiser 905 provides fine tuning across a relatively narrow range to achieve finer channel selection for the reception or transmission of ICO signals. During reception, the coarse and fine tuning of the UHF and VHF synthesisers provides the desired satellite signal in

one of five reception channels at the base band stage. The five reception channels are adjacent to one another and correspond to the satellite channels with the labels -2, -1, 0, +1, and +2 in Figure 10. By incorporating additional digital tuning in base band, selectivity of the desired satellite channel from the five possible reception channels is achieved. Digital base band tuning of this kind is described in the applicant's co-pending UK application GB 9605240.2, a copy of which is enclosed herewith in annex A.

Figure 13 presents suitable values for the UHF synthesiser 903 and VHF synthesiser 905 when receiving ICO satellite signals from channels 8 to 23. Similarly, Figure 14 presents suitable values for the UHF synthesiser 903 and VHF synthesiser 905 in Figure 9 when transmitting ICO satellite signals from channels 8 to 23. The UHF synthesiser 903 varies across the full 30 MHz bandwidth associated with the ICO transmit and receive bands, whereas the VHF synthesiser 905 varies across a relatively narrower frequency range centred around 232 MHz. As such, the VHF synthesiser 905 can tune in finer steps of 100 KHz during transmission and reception because the maximum frequency jump of the VHF synthesiser when hopping between channels is not large enough to significantly effect the total settling time of the transmitter or receiver. The column labelled SLOT in Figure 13 indicates which of the satellite channels shown in Figure 10 the desired satellite signals is located when it is fed to base band. The column labelled SLOT in Figure 14 indicates the base band frequency offset required for mixing with the modulation signal in the mixer 910.

The GSM and ICO transmit and receive paths, which correspond to the respective transmit and receive operations of the radio frequency circuits of Figures 9, may be provided with signal amplification stages and intermediate frequency bandpass filter stages for improving the respective transmit or receive signals. For example, the received GSM signal in Figure 9 may be amplified after passing through the GSM bandpass filter 902 prior to supplying the mixing unit 901. Similarly, the transmit GSM signal may be amplified after the mixing unit 913 prior to being transmitted by the terrestrial antenna 306b. Also, the

received ICO signal in Figure 9 may be amplified after passing through the ICO bandpass filter 915 prior to supplying the mixing unit 916. Similarly the transmit ICO signal may be amplified after the mixing unit 917 prior to being transmitted by the satellite antenna 307b.

Intermediate frequency bandpass filters may be provided at the 71 MHz and 13 MHz intermediate frequency stages during reception and at the 116 MHz intermediate frequency stage during transmission to provide added selectivity and to reject interference from adjacent channels. These intermediate frequency bandpass filters may have a bandwidth of 200 KHz, equal to the channel bandwidth in the GSM system. In this way the intermediate frequency bandpass filters can provide the single channel selectivity for the GSM signals having a channel bandwidth of 200 KHz and still permit the passage of ICO signals having a channel bandwidth of 25 KHz. The operation of the intermediate frequency bandpass filters is illustrated schematically in Figure 10. The dotted line shows the bandpass filter centred on the intermediate frequency F and having a total bandwidth of 200 KHz. The intermediate frequency bandpass filter allows the progress of satellite channels having an offset from F of up to +/- 75 KHz. As such, the 13, 71, and 116 MHz intermediate frequency satellite signals, presented in Figures 13 and 14, each have sufficiently small offsets to enable them to progress through the respective 200 KHz intermediate bandpass filters.

It should be understood that the foregoing description is only illustrative of the invention. Various alternatives and modifications can be devised by those skilled in the art without departing from the invention. Accordingly, the present invention is intended to embrace all such alternatives, modifications and variances which fall within the scope of the appended claims. For example, the satellite systems, ICO and IRIDIUM referred to in the specific embodiments may alternatively be other types of satellite system such as ODYSSEY or GLOBALSTAR. Equally, the GSM terrestrial system referred to in the specific embodiment may be another type of terrestrial system such as DECT or DCS 1800.

The present invention includes any novel feature or combination of features disclosed herein either explicitly or any generalisation thereof irrespective of whether or not it relates to the claimed invention or mitigates any or all of the problems addressed.

CLAIMS

1. A method for receiving a radio frequency signal of a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the method comprising the steps of:

processing the radio frequency signal in combination with a first analogue demodulating signal to produce a first analogue intermediate signal, and

processing the first analogue intermediate signal in combination with a second analogue demodulating signal to produce a second analogue intermediate signal, wherein the frequency resolution of the first analogue demodulating signal is wider than the channel spacing, and the frequency resolution of the second analogue demodulating signal is finer than the frequency resolution of the first analogue demodulating signal, and the frequencies of the first and second analogue demodulating signals are adjusted in accordance with their respective frequency resolutions in order to tune the receiver to the radio frequency signal.

2. A method as claimed in claim 1, wherein adjustment of the first and second demodulating signals tunes the receiver to the channel frequency of the radio frequency signal.

3. A method as claimed in claim 1, wherein adjustment of the first and second demodulating signals tunes the receiver to a channel frequency in the vicinity of the radio frequency signal in order for a digital tuning process to further tune the receiver to the channel frequency of the radio frequency signal.

4. A method as claimed in any one of the preceding claims, wherein the first analogue intermediate signal is processed in combination with a further analogue demodulating signal before being processed in combination with the second analogue demodulating signal.

5. A method for transmitting a modulation signal in a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the method comprising the steps of:

processing the modulation signal in combination with a first analogue modulating signal to produce an analogue intermediate signal, and

processing the analogue intermediate signal in combination with a second analogue modulating signal to produce a radio frequency output signal at a channel frequency of the multiple channel radio system, wherein the frequency resolution of the second analogue modulating signal is wider than the channel spacing, and the frequency resolution of the first analogue modulating signal is finer than the frequency resolution of the second analogue modulating signal, and the frequencies of the first and second analogue modulating signals are adjusted in accordance with their respective frequency resolutions so as to change the channel frequency of the output signal.

6. A method as claimed in claim 5, wherein the radio frequency output signal is processed in combination with a further modulating signal before being transmitted.

7. A method as claimed in any one of the preceding claims, wherein the processing steps comprise mixing one signal in combination with another signal.

8. A method as claimed in any one of the preceding claims, wherein the modulating or demodulating signals are produced by frequency synthesisers.

9. A method as claimed in any one of the preceding claims, wherein the first and second modulating or demodulating signals are produced by separate frequency synthesisers.

10. A method as claimed in any one of claims 1 to 8, wherein one of the modulating or demodulating signals is produced by a combined output of two frequency synthesisers.

11. A method as claimed in any one of the preceding claims, wherein the frequency resolution of the second analogue demodulating signal or the first analogue modulating signal is equal to the channel spacing.

12. A method as claimed in any one of claims 1 to 10, wherein the frequency resolution of the second analogue demodulating signal or the first analogue modulating signal is greater than a channel spacing.

13. Radio frequency receiving apparatus for receiving a radio frequency signal of a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the apparatus comprising:

signal generating means for producing a first analogue demodulating signal with a frequency resolution wider than the channel spacing, and a second analogue demodulating signal with a frequency resolution finer than the first analogue demodulating signal,

first processing means for processing the radio frequency signal in combination with the first analogue demodulating signal to produce a first analogue intermediate signal,

second processing means for processing the first analogue intermediate signal in combination with the second analogue demodulating signal to produce a second analogue intermediate signal, and

adjusting means arranged in cooperation with the signal generating means to adjust the frequencies of the first and second demodulating signals in accordance with their respective frequency resolutions in order to tune the receiver to the radio frequency signal.

14. Apparatus as claimed in claim 13, wherein adjustment of the first and second demodulating signals tunes the receiver to the channel frequency of the radio frequency signal.

15. Apparatus as claimed in claim 13, wherein adjustment of the first and second demodulating signals tunes the receiver to a channel frequency in the vicinity of the radio frequency signal, and the apparatus further comprises digital tuning means to further tune the receiver to the channel frequency of the radio frequency signal.

16. Apparatus for transmitting a modulation signal in a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the apparatus comprising:

signal generating means for producing a second analogue modulating signal with a frequency resolution wider than the channel spacing, and a first analogue modulating signal with a frequency resolution finer than the second analogue modulating signal,

first processing means for processing the modulation signal in combination with the first analogue modulating signal to produce an analogue intermediate frequency signal,

second processing means for processing the analogue intermediate signal in combination with the second analogue modulating signal to produce a radio frequency output signal, and

adjusting means arranged in cooperation with the signal generating means to adjust the frequencies of the first and second modulating signals within their respective frequency resolutions so as to change the channel frequency of the output signal.

17. Apparatus as claimed in any one of claims 13 to 16, wherein the signal generating means comprises a first synthesiser for producing the first analogue modulating or demodulating signal, and a second synthesiser for producing the second analogue modulating or demodulating signal.

18. Apparatus as claimed in any one of the claims 13 to 17, wherein the first and/or second processing means comprises a mixing unit.

19. A method for receiving a radio frequency signal of a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the method comprising the steps of:

processing the radio frequency signal in combination with a first analogue demodulating signal to produce a first analogue intermediate signal, and

processing the first analogue intermediate signal in combination with a second analogue demodulating signal to produce a second analogue intermediate signal, wherein the frequency resolution of the second analogue demodulating signal is wider than the channel spacing, and the frequency resolution of the first analogue demodulating signal is finer than the frequency resolution of the second analogue demodulating signal, and the frequencies of the first and second analogue demodulating signals are adjusted in accordance with their respective frequency resolutions in order to tune the receiver to the radio frequency signal.

20. A method for transmitting a modulation signal in a multiple channel radio system, in which each channel has an associated channel frequency and the channel frequencies of adjacent channels are separated by a channel spacing, the method comprising the steps of:

processing the modulation signal in combination with a first analogue modulating signal to produce an analogue intermediate signal, and

processing the analogue intermediate signal in combination with a second analogue modulating signal to produce a analogue radio frequency output signal, wherein the frequency resolution of the first analogue modulating signal is wider than the channel spacing, and the frequency resolution of the second analogue modulating signal is finer than the frequency resolution of the first analogue modulating signal, and the frequencies of the first and second analogue modulating signals are adjusted in accordance with their respective frequency resolutions so as to change the channel frequency of the output signal.

21. A radio telephone operable with an apparatus or a method as claimed in any preceding claim.

22. A method of receiving a radio frequency signal as described herein with particular reference to Figure 8 of the accompanying drawings.

23. A method of transmitting a modulation signal as described herein with particular reference to Figure 8 of the accompanying drawings.

24. A radio frequency receiver as described herein with particular reference to Figure 8 of the accompanying drawings.

25. A radio frequency transmitter as described herein with particular reference to Figure 8 of the accompanying drawings.

26. A radio frequency transceiver as described herein with particular reference to Figure 8 of the accompanying drawings.

27. A method of receiving a radio frequency signal as described herein with particular reference to Figure 9 of the accompanying drawings.

28. A method of transmitting a modulation signal as described herein with particular reference to Figure 9 of the accompanying drawings.

29. A radio frequency receiver as described herein with particular reference to Figure 9 of the accompanying drawings.

30. A radio frequency transmitter as described herein with particular reference to Figure 9 of the accompanying drawings.

31. A radio frequency transceiver as described herein with particular reference to Figure 9 of the accompanying drawings.

ABSTRACT

A method and apparatus for receiving a radio frequency signal and a method and apparatus for transmitting a modulation signal in a multiple channel radio system. The method for receiving the radio frequency signal involves mixing the radio frequency signal with a demodulating signal, tunable in frequency steps greater than the channel spacing of the multiple channel radio system to facilitate rapid frequency adjustments. The resultant intermediate signal is then mixed with another demodulating signal, tunable in relatively smaller frequency steps in order to select the channel containing the radio frequency signal.

Fig. 1

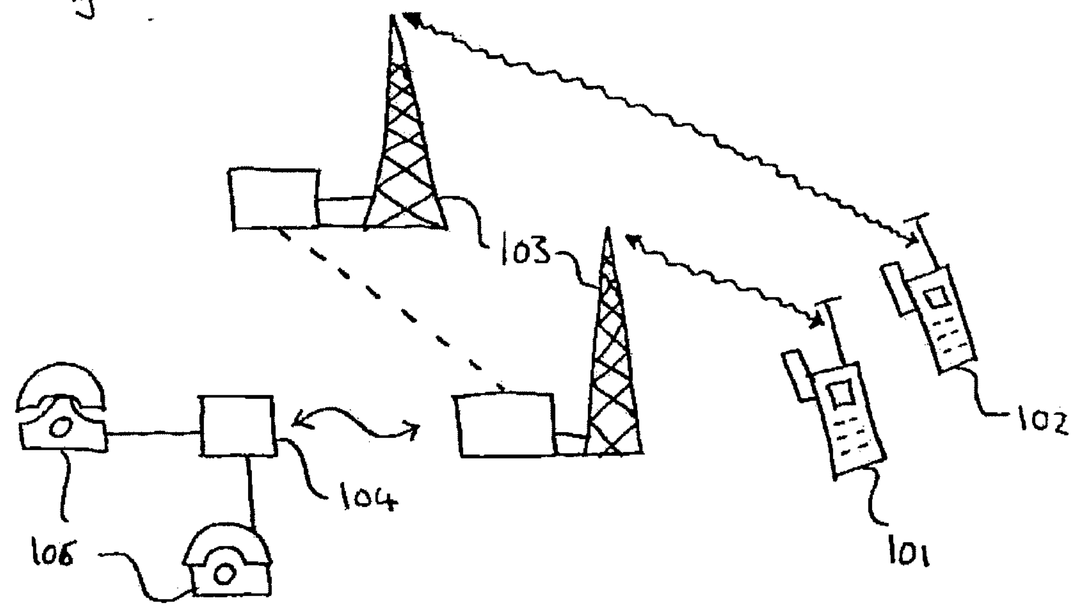
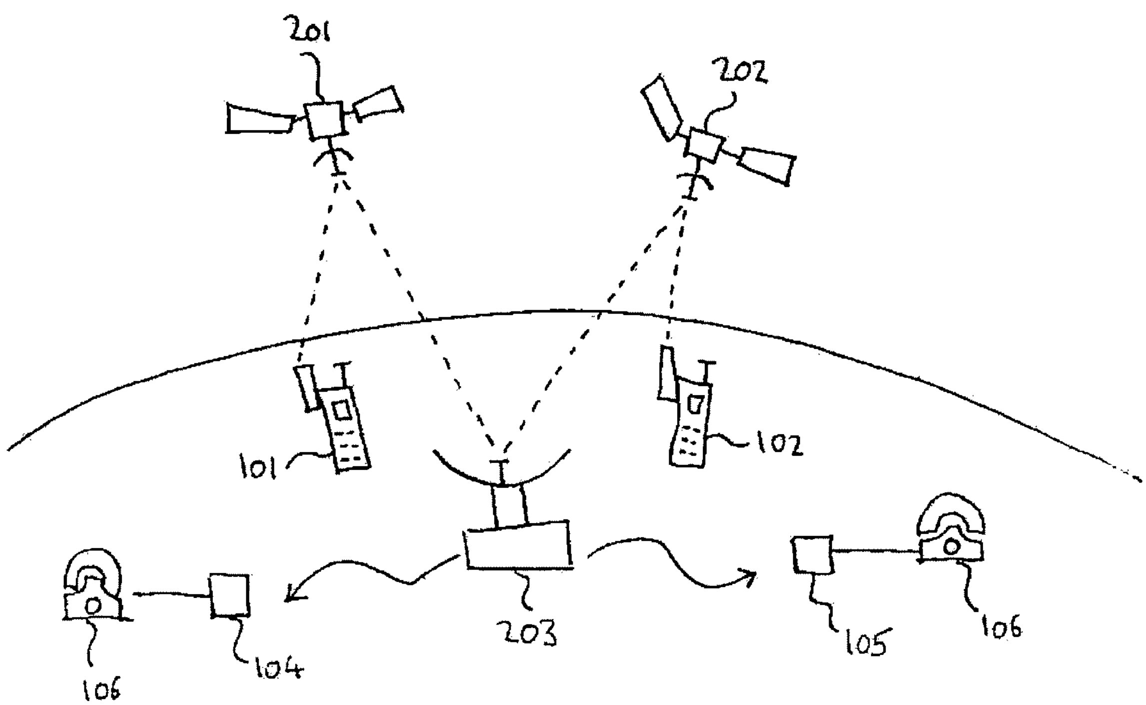
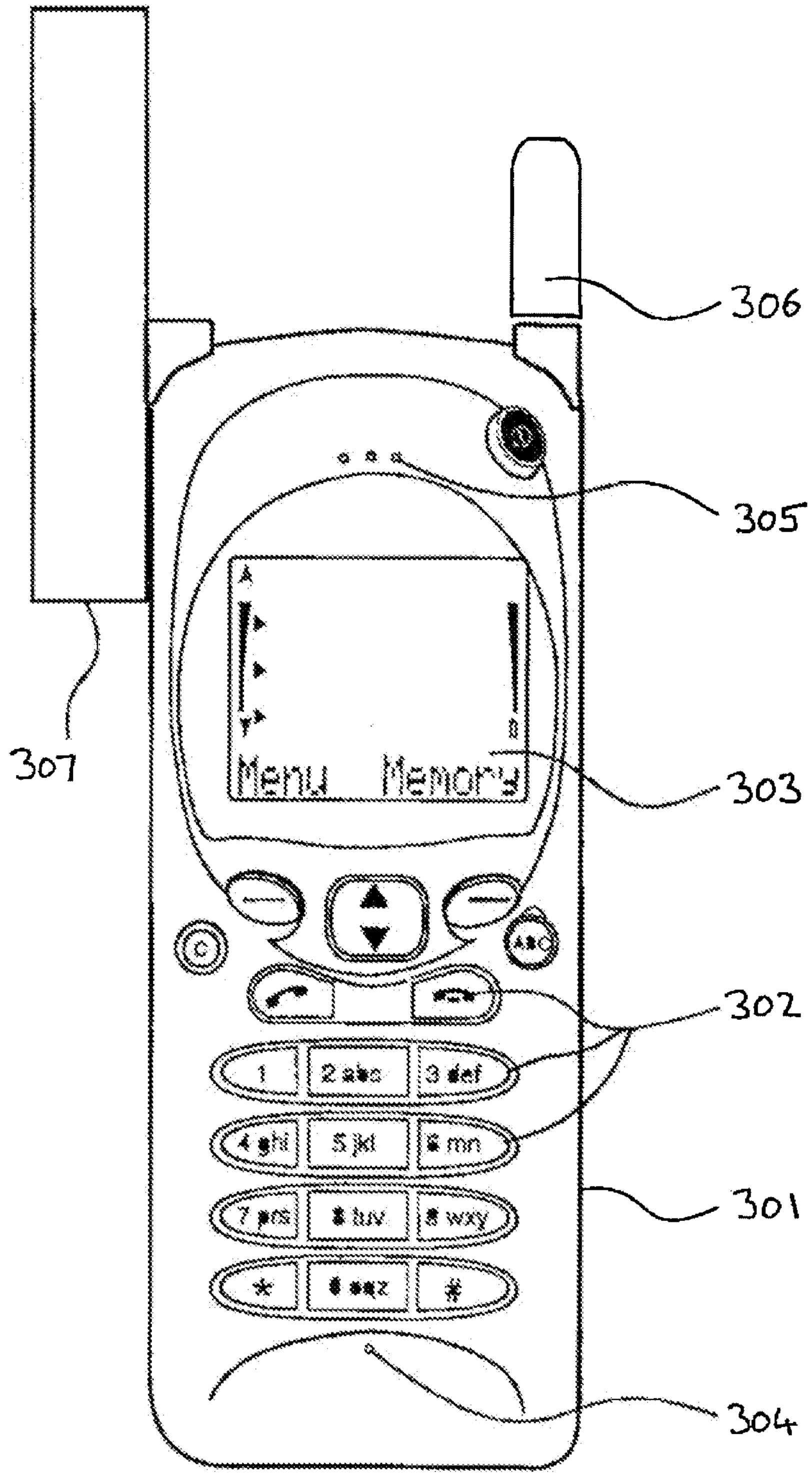


Fig. 2





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307
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303
1
2 abc
3 def
4 ghi
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6 mn
7 prs
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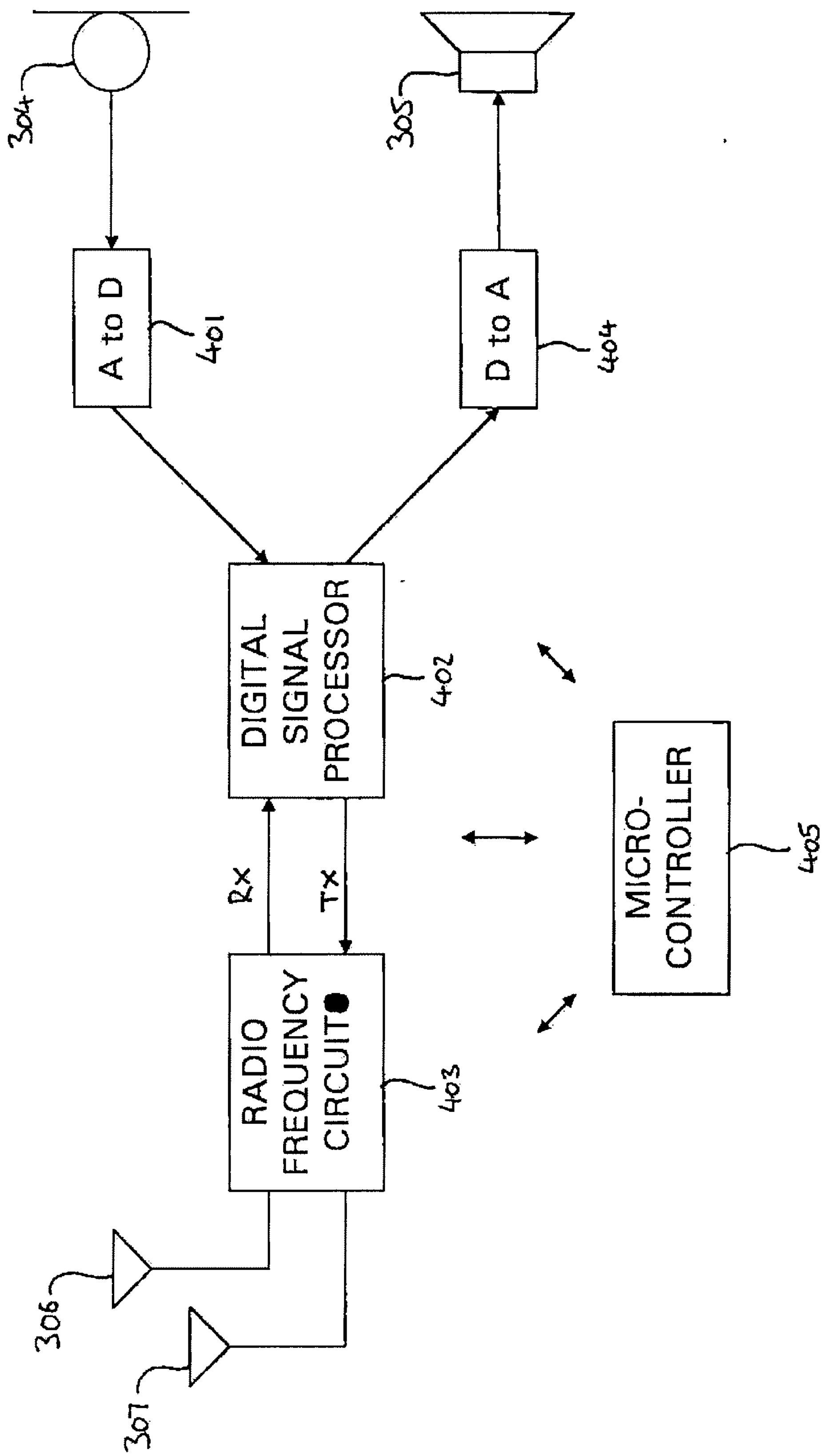
302
301
304

Fig. 3

Fig. 4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A to D
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D to A
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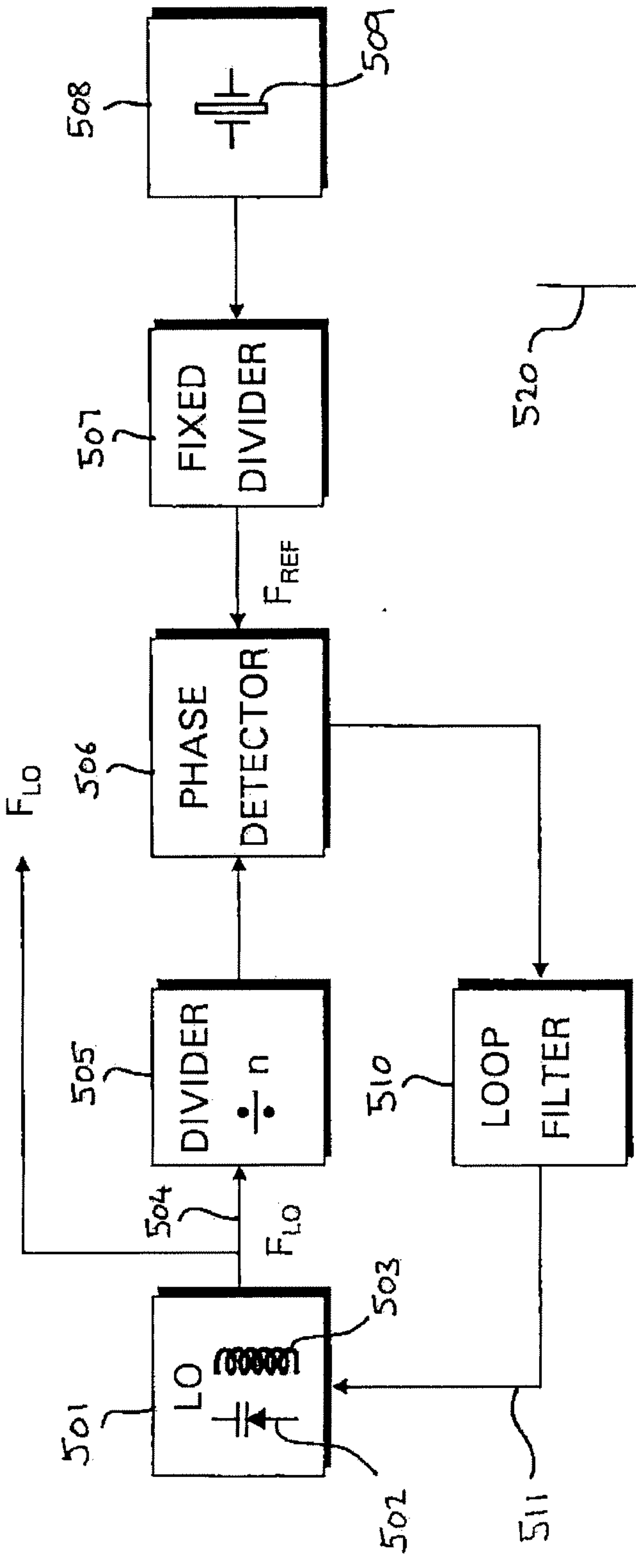
Rx
Tx
MICRO-CONTROLLER
405
RADIO FREQUENCY CIRCUIT
403
306
307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504
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DIVIDER
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PHASE DETECTOR
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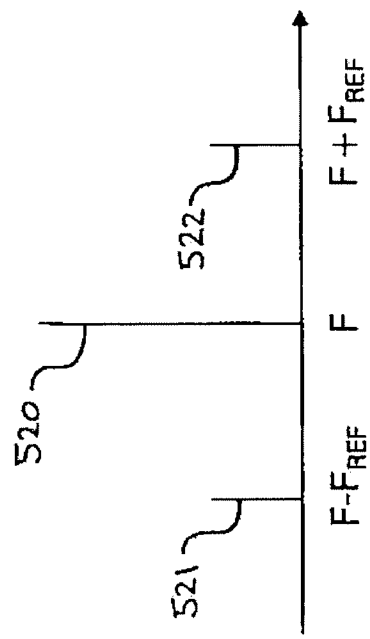
507
F_{REF}
508
509
LOOP FILTER
510
511

Fig. 5A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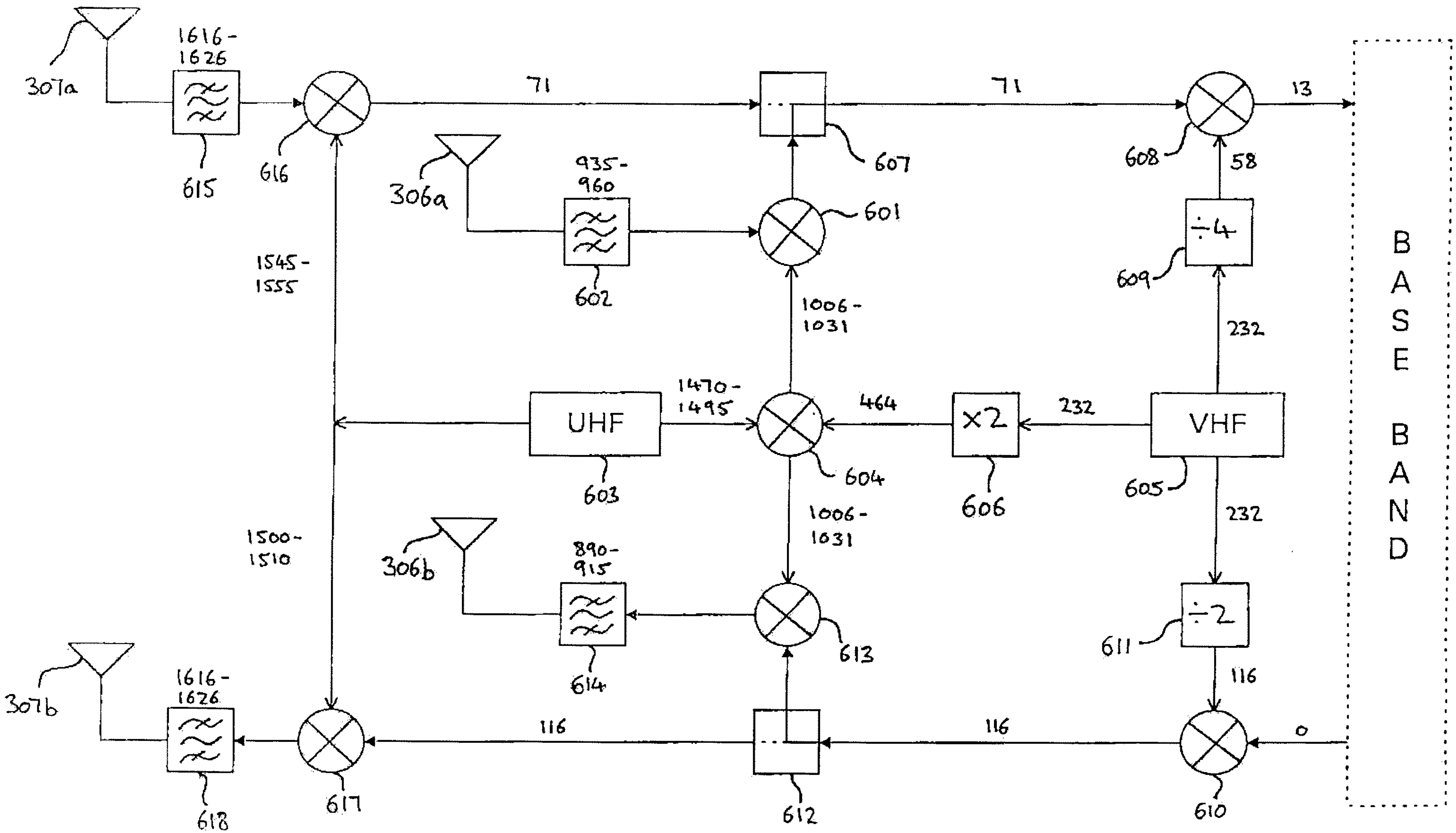
$F+F_{REF}$

Fig. 5B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÷2
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71
58
232
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232
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116
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1616-1626
1616-1626
935-960
890-915
1006-1031
1006-1031
1470-1495
1545-1555
1500-1510
307a
307b
306a
306b
601
602
603
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605
606
607
608
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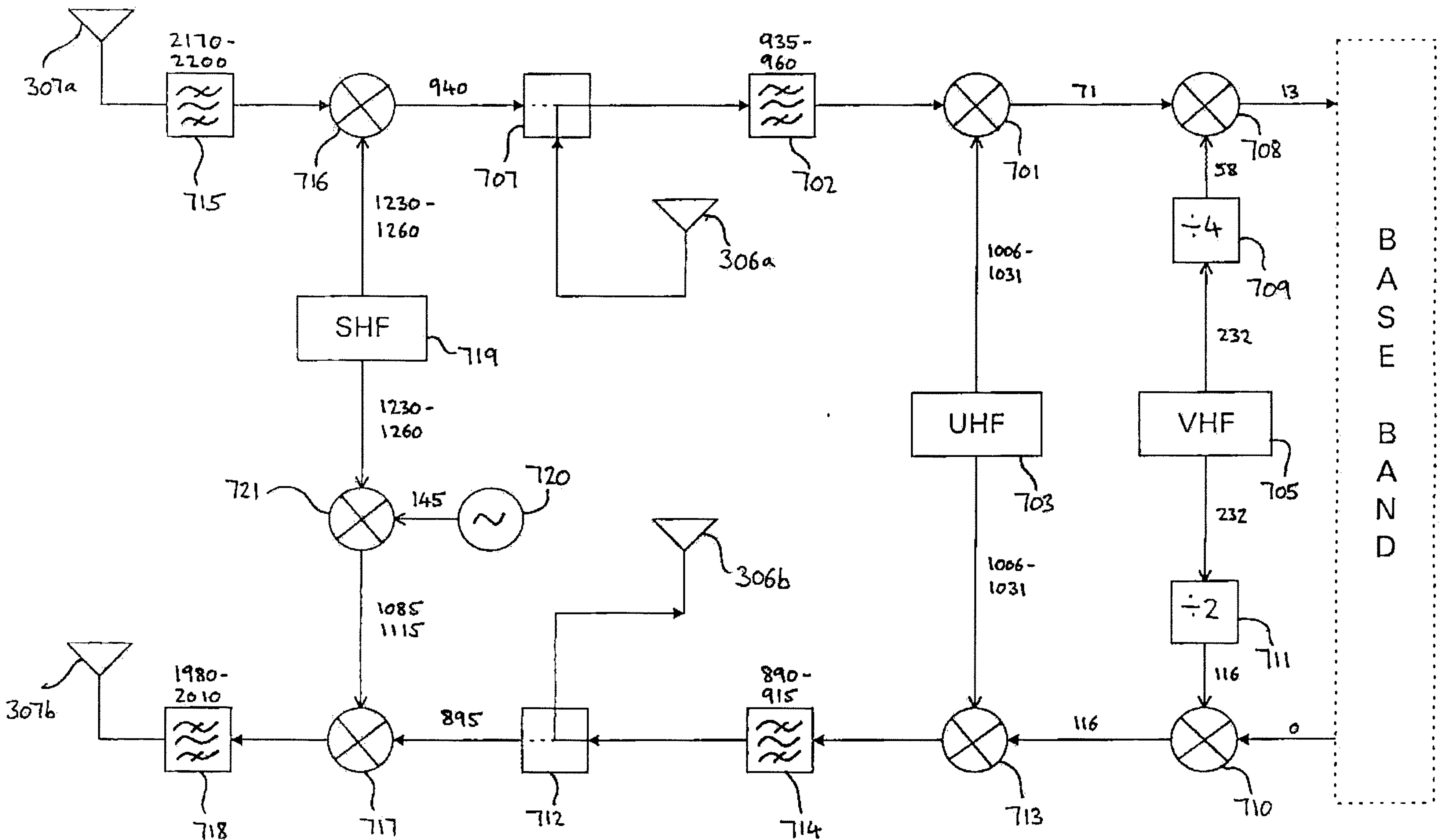
615
616
617
618

Fig. 6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715
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940
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935-
960
702
701
71
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13
58
709
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1260
SHF
719
306a
1006-
1031
UHF
703
232
VHF
705
1230-
1260
721
145
720
306b
1006-
1031
232
÷4
÷2
711
1085
1115
116
307b
1980-
2010
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717
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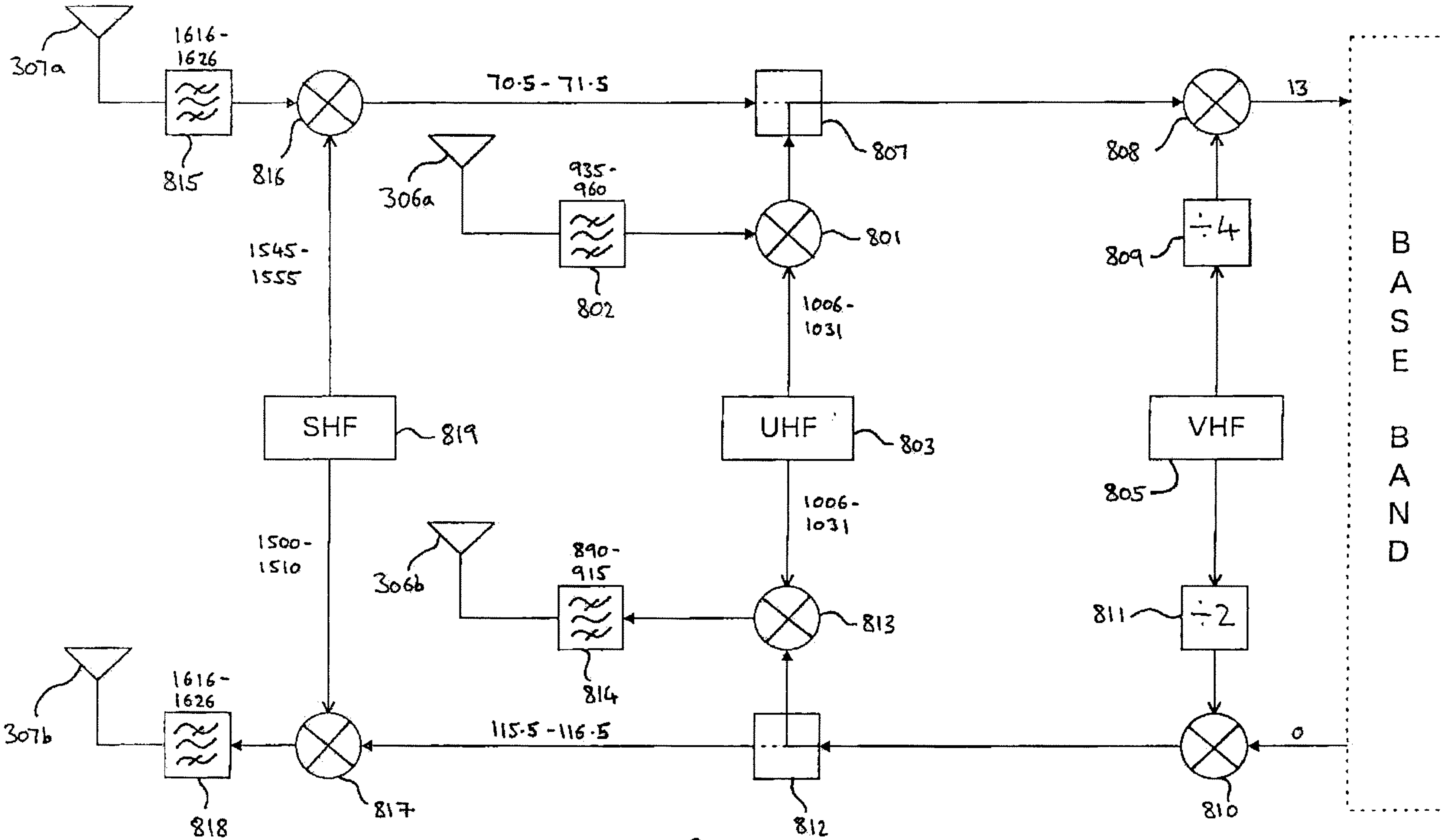
712
890-
915
714
713
116
710
0

Fig. 7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815
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13
306a
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801
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÷4
1545-
1555
1006-
1031
SHF
819
UHF
803
VHF
805
BASE BAND
1500-
1510
1006-
1031
306b
890-
915
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813
811
÷2
307b
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818
817
115.5 - 116.5
812
810
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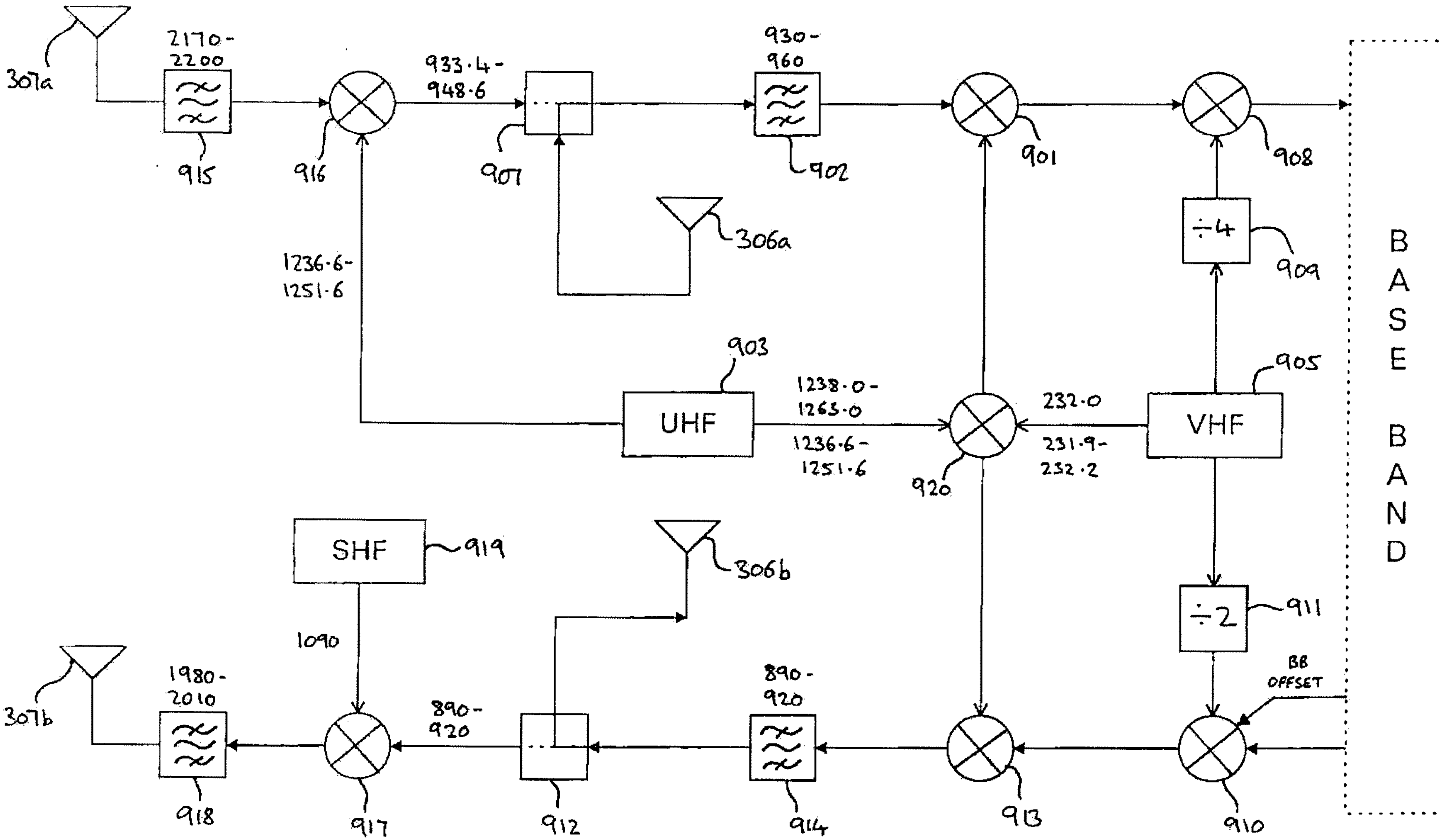
Fig. 8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916
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948·6
907
930-
960
902
901
908
306a
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909
1236·6-
1251·6
903
UHF
1238·0-
1263·0
1236·6-
1251·6
920
232·0
231·9-
232·2
VHF
905
B A S E B A N D
SHF
919
306b
÷2
911
1090
BB
OFFSET
307b
1980-
2010
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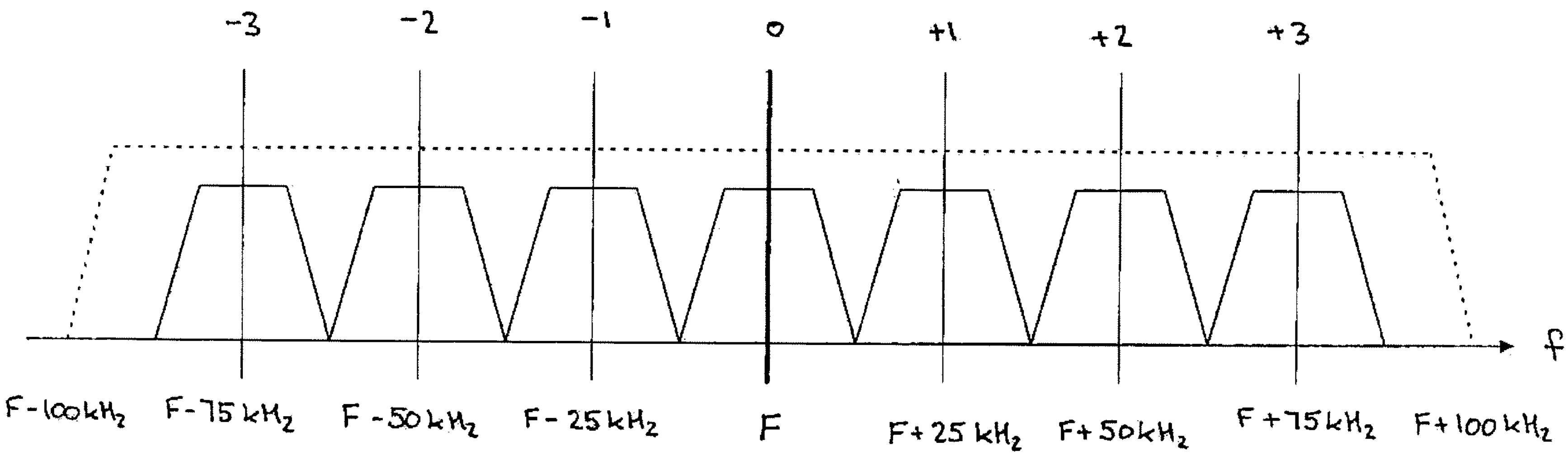
917
890-
920
912
890-
920
914
913
910

Fig. 9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+1
+2
+3
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F-100kHz
F-75kHz
F-50kHz
F-25kHz
F
F+25kHz
F+50kHz
F+75kHz
F+100kHz

Fig. 10

CHANNEL	IRIDIUM INPUT (MHz)	SHF (MHz)	VHF (MHz)	IRIDIUM IF1 (MHz)	IRIDIUM IF2 (MHz)
8	1616.333	1545.0	233.333	71.333	13.000
9	1616.375	1545.0	233.500	71.375	13.000
10	1616.417	1545.0	233.667	71.417	13.000
11	1616.458	1545.0	233.833	71.458	13.000
12	1616.500	1546.0	230.000	70.500	13.000
13	1616.542	1546.0	230.167	70.542	13.000
14	1616.583	1546.0	230.333	70.583	13.000
15	1616.625	1546.0	230.500	70.625	13.000
16	1616.667	1546.0	230.667	70.667	13.000
17	1616.708	1546.0	230.833	70.708	13.000
18	1616.750	1546.0	231.000	70.750	13.000
19	1616.792	1546.0	231.167	70.792	13.000
20	1616.833	1546.0	231.333	70.833	13.000
21	1616.875	1546.0	231.500	70.875	13.000
22	1616.917	1546.0	231.667	70.917	13.000
23	1616.958	1546.0	231.833	70.958	13.000

Fig. 11

CHANNEL	VHF (MHz)	IRIDIUM IF1 (MHz)	SHF (MHz)	IRIDIUM OUTPUT (MHz)
8	232.667	116.333	1500.0	1616.333
9	232.750	116.375	1500.0	1616.375
10	232.833	116.417	1500.0	1616.417
11	232.917	116.458	1500.0	1616.458
12	231.000	115.500	1501.0	1616.500
13	231.083	115.542	1501.0	1616.542
14	231.167	115.583	1501.0	1616.583
15	231.250	115.625	1501.0	1616.625
16	231.333	115.667	1501.0	1616.667
17	231.417	115.708	1501.0	1616.708
18	231.500	115.750	1501.0	1616.750
19	231.583	115.792	1501.0	1616.792
20	231.667	115.833	1501.0	1616.833
21	231.750	115.875	1501.0	1616.875
22	231.833	115.917	1501.0	1616.917
23	231.917	115.958	1501.0	1616.958

Fig. 12

CHANNEL	ICO INPUT (MHz)	UHF (MHz)	VHF (MHz)	ICO IF1 (MHz)	ICO IF2 (MHz)	IF2 OFFSET (KHz)	ICO IF3 (MHz)	IF3 OFFSET (KHz)	SLOT
8	2170.200	1236.6	232.0	933.600	71.000	-	13.000	-	-
9	2170.225	1236.6	232.0	933.625	70.975	-25	12.975	-25	-1
10	2170.250	1236.6	232.0	933.650	70.950	-50	12.950	-50	-2
11	2170.275	1236.6	231.9	933.675	71.025	+25	13.050	+50	+2
12	2170.300	1236.6	231.9	933.700	71.000	-	13.025	+25	+1
13	2170.325	1236.6	231.9	933.725	70.975	-25	13.000	-	-
14	2170.350	1236.6	231.9	933.750	70.950	-50	12.975	-25	-1
15	2170.375	1236.6	231.9	933.775	70.925	-75	12.950	-50	-2
16	2170.400	1236.8	232.2	933.600	71.000	-	12.950	-50	-2
17	2170.425	1236.8	232.1	933.625	71.075	+75	13.050	+50	+2
18	2170.450	1236.8	232.1	933.650	71.050	+50	13.025	+25	+1
19	2170.475	1236.8	232.1	933.675	71.025	+25	13.000	-	-
20	2170.500	1236.8	232.1	933.700	71.000	-	12.975	-25	-1
21	2170.525	1236.8	232.1	933.725	70.975	-25	12.950	-50	-2
22	2170.550	1236.8	232.0	933.750	71.050	+50	13.050	+50	+2
23	2170.575	1236.8	232.0	933.775	71.025	+25	13.025	+25	+1

Fig. 13

CHANNEL	SLOT	BB OFFSET (KHz)	VHF (MHz)	UHF (MHz)	ICO IF1 (MHz)	IF OFFSET	ICO IF2 (MHz)	ICO OUTPUT (MHz)
8	-		3 0 2 3	3	00 16		8 2 0.	9 0 8 200
9 1	-1	-2 5	2.	1 8 2	1	-2 5	8 9 2 0 0	19 0
1 0	-2		2 0	1 2 38	1 9 0		0 9 2 5	2 5 8 0
1	2 4	-50 5	3 2 2		1 1 5 .9 5	+50	8 0 25	1 2 2 0
12	+		0	1 2 3 2 8	1 6 07 1 5	2	9 2	98 0 19 2 5 5
13	+1	2 0 5	3 2 2 1	3 1 2 8 4 2	1 5 00 5 11 6 50	-5 2 +5	8 0 50 8 90 3 2 0	9 1 8 3 7
1 4	+2	5 +	3 2 2 1	8 1 2 3 8	6 9 1 1 2 0	5 +	8 7 8 90 3	9 1 80 0
15	1	+2 5	3 2	1 4 2 3	1 1 6 0 5	2 0	8 90 3 7 0 5	9 3 0 8 1 8 0 3 7
2 1	2	+ 5	32 9 2 1 0	1 8 2 2 3 4	1 1 6 0 7 5 0	+	8 90 3 5 50	9 8 0 2 3 0 1 80
2	1	+50	232	1 2 3	1 1 5 0 5 0 5 5	-25	90 4 0 89	9 50 25
1 6	+	-2 0	2 0	1 2 3 8 2	1 5 9	2 50	8 90 0	19 80
22	2	+2	2 2	1 2 3 8 2	1	+ 5	890. 2 0	19 80 450
1 7	+ 1	-50	3 2 0 2	1 2 38 4	116 8 9 2 2 0	5	8 9 25	19 8 475 0
23 1 8		+ 5	3 2	1 2 3 8 4	11 6 0 00 5	+2 2	9 0 4 50 8	1 98 80 4 5 0
	2		32		11 5 70	5 5	90 4 7 0	19
9	1	2 5	3 1 0	1 3 8 4	1 00 5 5		8 9 4 0 5 5	0 475 2 98
0			2 2 1 9	12 8 4	9	50	0	0 50 5 5 9
1		5 0	32 0 1	2 3 8 8	0		8 5 5	5
			32 2 0	2 6	02		0 5	
—		5		6			5	5
		2		4			5	5
		5		6				

F . 9.

ANNEX A

PAT 96014 GB

TRANSMITTING AND RECEIVING RADIO SIGNALS

The present invention relates to transmitting and receiving radio signals.

INTRODUCTION

Radio signals may be generated or selected by means of a tuned circuit comprising inductive and capacitive elements, typically a coil and a capacitor. The combination of these elements connected in parallel or in series has a characteristic resonant frequency, that may be used to define the frequency of transmission or reception of the radio circuit. Modification of either of these components results in a change in the resonant frequency. Historically, a continuously variable capacitor has been used to tune over a particular waveband.

More recently new methods for modifying the characteristic resonant frequency of tuned circuits have been developed. In particular, the replacement of the variable capacitor with a varicap diode, also known as a varactor, enables the tuned circuit to be controlled by a voltage. The varicap diode is a reversed biased diode and by modifying the magnitude of a reverse voltage across the diode, the depletion layer, which prevents conduction, varies in thickness and acts as a variable capacitor.

In a tuned circuit that includes a varicap diode, the relationship between control voltage and resonant frequency is neither convenient nor particularly stable. Accurate control of resonant frequency is accomplished by including the tuned circuit in a radio frequency oscillator which forms part of a phase-locked loop. The output from the radio frequency oscillator may then be supplied to transmission or reception circuitry in order to define the frequency of transmitted or received radio signals.

SUMMARY OF THE INVENTION

According to a first aspect of the present invention, there is provided a method of transmitting a digital input signal over a radio channel, comprising steps of: processing said digital input signal in combination with a digital modulating signal to produce a digital intermediate signal; converting said digital signal into an analog intermediate signal; and processing said analog intermediate signal in combination with an analog modulating signal to produce a radio frequency output signal, wherein the frequency of said digital modulating signal and the frequency of said analog modulating signal are adjusted to change the frequency of said output signal.

According to a second aspect of the present invention, there is provided a method of receiving the radio frequency signal, comprising steps of: processing said signal in combination with an analog demodulating signal to produce an analog intermediate signal; sampling said analog intermediate signal to produce a digitized intermediate signal; and processing said digital intermediate signal in combination with a digital demodulating signal to select a transmission channel, wherein the frequency of said digital demodulating signal and the frequency of said analog demodulating signal are both adjusted to accommodate changes in said received signal.

Preferably, the intermediate signal is processed in combination with an additional analog demodulating signal before being sampled.

Preferably, the resolution of the analog modulating or demodulating signal is wider than a channel spacing to facilitate rapid frequency adjustments and individual channels are selected by a finer frequency resolution during the digital processing step.

According to a third aspect of the present invention there is provided apparatus for transmitting a digital input signal over a radio channel, comprising: processing means for processing said digital input signal in combination with a digital

modulating signal to produce a digital intermediate signal; converting means for converting said digital intermediate signal into an analog intermediate signal; and processing means for processing said analog intermediate signal in combination with an analog modulating signal to produce a radio frequency output signal, including means arranged to adjust the frequency of said digital modulating signal and arranged to adjust the frequency of said analog modulating signal so as to change the frequency of said output signal.

According to a fourth aspect of the present invention there is provided radio frequency receiving apparatus, comprising: processing means for processing a received signal in combination with an analog demodulating signal to produce an analog intermediate signal; sampling means for sampling said analog intermediate signal to produce a digital intermediate signal; and processing means for processing said digital intermediate signal in combination with a digital demodulating signal to select a transmission channel, including means for adjusting the frequency of said analog demodulating signal and means for adjusting the frequency of said digital demodulating signal to accommodate variations in the frequency of said received signal.

In a preferred embodiment, the apparatus includes means for processing said intermediate signal in combination with an additional analog demodulating signal before said intermediate signal is sampled. Preferably, the resolution of the analog modulating signal or the analog demodulating signal is wider than a channel spacing, to facilitate rapid frequency adjustments; and individual channels are selected by a finer frequency resolution by the digital processing apparatus. Radio signals may be susceptible to Doppler shifts and Doppler shift compensation may be provided by adjusting the frequency of the digital modulating or digital demodulating signals in the digital signal processing domain.

DESCRIPTION OF DRAWINGS

Figure 1 shows the block diagram of the general principles involved in radio frequency synthesis;

Figure 2 shows an improved method of radio frequency synthesis;

Figure 3 shows a satellite telecommunications system, including satellites and mobile telephone transceivers;

Figure 4 shows a graph of the times required for transmission and reception between a satellite and a telephone transceiver of the type shown in Figure 3;

Figure 5 shows a mobile telephone transceiver of the type shown in Figure 3;

Figure 6 shows a block diagram of the circuitry operating inside the mobile telephone transceiver shown in Figure 5, including a digital signal processor, a transmitter and a receiver;

Figure 7 details processes performed by the digital signal processor and transmitter shown in Figure 6, including a transmitter, an IQ modulator and an IQ upconverter;

Figure 8 details processes performed by the digital signal processor and receiver shown in Figure 6, including an analog receiver, an IQ downconverter and a digital IQ demodulator;

Figure 9 details the transmitter IQ processes shown in Figure 7, including a phase splitter;

Figure 10 details the phase splitter shown in Figure 9;

Figure 11 details radio frequency spectra arising from non-linearities in the transmitter chain;

Figure 12A details the analog receiver IQ processes shown in Figure 8; and

Figure 12B details the digital receiver IQ demodulator shown in Figure 8.

THE PREFERRED EMBODIMENT

The invention will now be described by way of example only, with reference to the drawings identified above.

A radio frequency phase-locked loop is shown in Figure 1. A radio frequency oscillator 101 contains a tuned circuit, having a resonant frequency defined by a varicap diode 102 and an inductor 103. The oscillator 101 is typically of the type known as a Hartley or Colpitts oscillator and a signal 104 is generated having a frequency FLO defined by the resonant frequency of the tuned circuit.

The oscillator output 104 is supplied to a divider 105, which divides the oscillator frequency, FLO, by an integer value, n. The divided frequency is supplied to a first input of a phase detector 106.

A reference oscillator 108 consists of a temperature-compensated crystal oscillator, having a quartz crystal 109. This oscillates at a fixed known frequency, which is divided by a fixed factor in the fixed divider 107. The output from the fixed divider 107 is known as the reference frequency, FREF, and is supplied to a second input of the phase detector 106.

The phase detector generates an output voltage dependent on the difference in phase between its two inputs. This is supplied to a low pass loop filter 110, the output voltage 111 of which being dependent on the difference in phase between the two signals supplied to the phase detector 106. The output 111 from the loop filter 110 supplies a control voltage to the varicap diode 102 in the oscillator 101. The loop filter 110 generates a signal which pulls the phase and frequency FLO of the oscillator 101 to a value, which after division by n in the variable divider 105, is equal to the phase and frequency of FREF, from the fixed divider 107.

Thus a classic phase-locked loop is formed, with the frequency FLO of the oscillator 101 being controlled by the integer, n, used in divider 105, and the channel spacing between increments of n being defined by the value of FREF. This arrangement illustrates the basic concepts used in a radio frequency synthesizer, more generally known as a radio frequency phase-locked loop.

Unfortunately the programmable divider 105 cannot operate at input frequencies of greater than a few tens of megahertz, without raising cost and power consumption to unacceptable levels. A possible solution is to pre-divide the signal 104 by some fixed value using a fixed high speed divider. This technique is known as prescaling. This creates an additional problem in that FREF must be divided by the same amount, since the channel spacing is now equal to FREF multiplied by the prescaling factor.

In phase-locked loop literature, the classic problem is feed-through of the FREF signal from the fixed divider 107, through the phase detector 106, to the signal 111 supplied to the oscillator 101. Removal of FREF from the output of the phase detector 106 is performed by the loop filter 110. However, if FREF is reduced to one-tenth of the channel spacing, the loop filter's low pass cutoff frequency must similarly be reduced by a factor of ten. The consequence of this is an increase in the loop settling time by a factor of ten. This may lead to long settling times, rendering the circuit useless when techniques such as fast frequency hopping are to be used.

The problem with the arrangement in Figure 1A is further explained in Figure 1B. Without extreme filtering, due to radio frequency feed-through, sidebands 121 and 122 are imposed on the output 104 from oscillator 101, which has a centre frequency 120. These sidebands will degrade or distort reception of the desired channel by adding unwanted modulation components. Furthermore, selectivity of adjacent reception channels will be reduced. A lower cut-off frequency could be used for the loop filter 110, in order to reduce the amplitudes of the sidebands 121

and 122, but this would result in an increase in the loop settling time. Thus narrow channel spacing and fast settling time are contradictory requirements, as is known in the art.

There is a known technique for allowing FREF to equal the channel spacing while maintaining low cost and power consumption. Figure 2 details a frequency synthesizer similar to that shown in Figure 1A, where the integer divider 105 is replaced by a more complex arrangement. A dual modulus prescaler 201 divides the frequency FLO of the output from the oscillator 101 by, for example, either one hundred or one hundred and one, depending on a selecting signal 204. The resulting divided frequency is supplied to both a Swallow counter 202, which divides by integer NS, and a programmable counter 203, which divides by integer NP. In known systems, other pairs of division constants may be used, such as ten and eleven, thirty and thirty-one, depending on the degree of prescaling that is required.

The resulting combination performs a process known as Swallow Counting. Initially the dual modulus prescaler 201 is set to divide the output 104 of oscillator 101 by one hundred and one. Furthermore, the Swallow counter 202 is initialized to a value of NS, and the counter 203 is initialized to a value of NP, which must be greater than the value of NS for the system to work properly. After the first one hundred and one pulses have been supplied to the dual modulus prescaler 201, the Swallow counter 202 decrements its value by one, and the counter 203 also decrements its value by one.

The dual modulus prescaler 201 continues to decrement the Swallow counter 202 and the counter 203 every one hundred and one pulses from signal 104, until the Swallow counter 202 contains zero. Upon reaching zero, the Swallow counter 202 generates a selecting signal 204, causing the dual modulus prescaler 201 to divide by one hundred, instead of one hundred and one. Also, after reaching zero, the Swallow counter stops counting, but the counter 203 continues, and is now decremented once for every one hundred pulses from the output 104 from the

oscillator 101. This continues until the value of the counter 203 reaches zero, when the contents of the two counters 202 and 203 are reset to their initial values of NS and NP respectively, and the dual modulus prescaler 201 starts dividing by one hundred and one again.

The output 206 from the counter 203 has frequency FO, which is given by:

$$FO = FLO/N$$

where $N = 101.NS + 100(NP\text{-}NS)$

simplifying to $N = NS + 100.NP$ when $NP > NS$

When the phase is locked, $FO = FREF$, so the frequency of the oscillator 101 is given by:

$$FLO = FREF.N$$

$$FLO = FREF(NS + 100.NP)$$

Thus a fairly simple high speed dual modulus prescaler 201 can be made to provide channel increments equal to FREF, if the Swallow counting technique is used. This is implemented in a wide variety of equipment from inexpensive consumer radios to sophisticated digital cellular telephones. The fundamental constraint is defined again by the relationship between channel spacing and the loop settling time of the phase-locked loop. Although Swallow counting greatly improves the performance of radio frequency synthesizers, greater demands are anticipated as radio communication standards become increasingly more sophisticated.

In order to achieve narrow channel spacing, the loop filter 110 must have a low frequency constant, in order to filter out the FREF component from the control signal 111 supplied to the radio frequency oscillator 101. In consumer radio synthesizer receivers, the loop settling time is not particularly important, as a delay of a fraction of a second or so for the receiving frequency to settle while tuning in a different station is unlikely to be noticed. However, in cellular telephone systems using Time Division Multiple Access (TDMA) the loop settling time may be critical.

Mobile radio transmission is subject to variations in signal strength due to reflections from obstacles such as buildings, trees and cars. The same radio signal may be received from several reflecting surfaces, resulting in constructive and destructive interference. The consequent changes in signal amplitude are known as Rayleigh fading. At any given moment in time, it is possible for some frequency channels to be rendered unusable by destructive interference.

The concept of frequency diversity is key to the solution of this and other interference problems in mobile radio systems. In the Global System for Mobile communications (GSM) specifications for digital cellular phones, frequency hopping is used, with a short transmission and reception burst occurring every 4.6 milliseconds, and each subsequent burst operating at a different frequency. Voice data is encoded in a redundant interleaved format, thus, if a particular frequency suffers interference, the missing data can be, at least partially, reconstructed from previous and subsequent bursts without communication being interrupted.

In the GSM recommendations, frequency hopping is performed on channels spaced 200kHz apart. The greatest demand placed on the loop settling time of the frequency synthesizer is when switching from a transmission burst to a reception burst. Reception bursts might occur almost immediately after a transmission burst. Thus, every 4.6 milliseconds, there might be a short transmission burst followed almost immediately by a short reception burst. Furthermore, there is a requirement for the cellular telephone to listen to broadcast signals from adjacent cells during periods between active communication transmission or reception timeslots. The same frequency synthesizer is used to define the frequencies of transmission and reception, so it is essential for the loop settling time to be sufficiently low to meet this demand.

The GSM standard was developed with an awareness of practical difficulties of this sort and the specification is sufficiently undemanding to allow known frequency synthesizers to be used. Other telecommunications standards are presently under development. A particular constraint on satellite-based telephone systems,

currently under development is the requirement for narrow channel spacing, in order to make economic exploitation of the available bandwidth viable.

Whereas GSM specifies a channel spacing of 200kHz, suggested spacings for some satellite telephone systems are as narrow as 12.5 Khz. This extremely narrow channel spacing conflicts directly with the need for fast channel hopping, as it implies a low frequency constant for the loop filter 110, and thus a long loop settling time. While the problem may be reduced to some extent by having a separate frequency synthesizer for transmission and reception, this is expensive, in terms of cost, power consumption and physical circuit size.

Several satellite telephone systems are currently under development by the major telecommunications companies. One of these is known commercially by the trade name Iridium, established originally by Motorola. Iridium uses a number of low Earth orbit satellites, thus radio transmitters in the mobile handsets and the satellites can operate at a lower power than if high Earth orbit satellites are used. Low Earth orbit satellites have two major disadvantages in that a larger number of satellites are required per unit area of coverage and substantial variable doppler shifts are encountered as the satellite moves across the sky.

In the satellite telephone system shown in Figure 3, mobile handsets 301 and 302 communicate with the nearest available satellite 303, transferring data and digitized voice signals in a two way radio communication link 304 for the duration of a call. The satellite 303 combines data from several simultaneous calls in a high bandwidth communication link 305 to an Earth-bound satellite base station 306. During a call it is possible for a different satellite 307 to move closer to the handset 302 than satellite 303, in which case a new link 305 is established in order to make the best use of the available satellite resources, and to avoid the possibility of a satellite 303 moving over the horizon and breaking the link before the call has ended.

Although each link 304 and 305, between a satellite 303 and 307 and mobile telephones 301 and 302, carries a simultaneous two way conversation, it is difficult to transmit and receive at the same time, as the transmitting circuit in the mobile telephone 301 would overload or even damage its own receiving circuit without sophisticated filtering. Thus transmission and reception typically occur in short bursts and at different times. Timing of transmission and reception in the mobile telephone 301 is illustrated in Figure 4. A transmission burst 401 is followed by a reception burst 402. There is a short period 403 during which neither transmission nor reception occur, so that the various circuits can settle.

Transmission and reception bursts are repeated every few milliseconds. Speech signals are compressed into short bursts during transmission and spread out again during reception, so an uninterrupted two way conversation can take place.

The satellite mobile telephone handset 301 shown in Figure 3 is detailed in Figure 5. Several buttons 502 enable various operations to be performed, including accepting a call, terminating a call, dialling a number, storing a telephone number in an alphabetical index, and so on. An alphanumeric liquid crystal display 503 provides an indication of the telephone's status, including such information as signal strength, remaining battery power, the number which has been dialled, and so on. A microphone 504 converts sound pressure waves into an electrical signals, and a loudspeaker 505 converts electrical signals into sound pressure waves. An antenna 506, tuned to the transmission band of two gigahertz, radiates electromagnetic waves at the transmission frequency during transmission, and during reception converts electromagnetic waves from the satellite 303 into an electrical signal.

The main functional components of the mobile telephone 301 are shown in Figure 6. The microphone 504 generates analog electrical signals which are supplied to an analogue to digital converter 601. The analog to digital converter 601 converts the analog signals into a stream of binary numerical values representing instantaneous analog voltages supplied by the microphone 504 at regular intervals.

Binary electrical signals representing the microphone sound pressure are supplied to a digital signal processor 602, which performs several processing functions on the sound signal before it is used to modulate a radio frequency signal. The digital signal processor 602 supplies a modulation signal to a transmitter circuit 603, which also receives a radio frequency signal from the frequency synthesizer 604. When transmitting, the output from the transmitter circuit 603 is supplied to the antenna 506 via a switch 608.

During reception, the antenna 506 supplies radio frequency signals via the switch 608 to a receiver circuit 605. The receiver circuit also receives a radio frequency signal from the frequency synthesizer 604. The receiver circuit 605 supplies signals to the digital signal processor 602, for conversion into binary electrical samples representing sound. These binary electrical samples are supplied from the digital signal processor 602 to a digital to analog converter 606, which converts these into an analog voltage. The analog voltage is supplied to the loudspeaker 505, for converting the analog signal into sound.

A microcontroller 607 is connected to the liquid crystal display 503 and the buttons 502 shown in Figure 5. It is also connected to the digital signal processor 602, and other parts of the telephone circuit. Instructions executed by the microcontroller 607 co-ordinate circuit operations in response to user activation of the buttons 502, and signals provided by the circuit, such as battery strength and signalling information extracted by the digital signal processor 602.

In known systems the signal supplied by the digital signal processor 602 to the transmitter circuit 603 is purely a modulation signal, in other words it has a zero centre frequency and does not affect the centre frequency of the channel on which the modulation signal is to be transmitted. Similarly, the signal supplied by the receiver circuit 605 to the digital signal processor 602 is independent of the channel on which it has been received. In such a system, the frequency synthesizer 604 is responsible for controlling the selection of channel frequencies.

In known systems, switching between transmission and reception, or fast frequency hopping, requires the frequency synthesizer 604 to settle to its new frequency in a short period of time 403, as indicated in Figure 4. When the channel spacing is 200kHz, as is the case with the terrestrial GSM cellular network, the loop settling time of the frequency synthesizer 604 is sufficiently short using known techniques. However, in proposed standards for satellite telephone systems, the channel spacing might be as low as 12.5kHz. This would require a much lower time constant for the loop filter in the frequency synthesizer 604, resulting in a long settling time, conflicting with proposals for the satellite system.

Processes in the transmission chain which overcome this problem are shown in Figure 7. The first process performed by the digital signal processor is data pre-processing 701. This is an elaborate multi-step process which translates data from the microphone circuit, and some signalling data, into redundant, encrypted, interleaved data bursts. The data processing 701 also includes filtering, thus generating signals suitable for supplying to the next stage of the processing chain. The resulting filtered serial bit stream is supplied to an IQ modulator 702, arranged to generate a quadrature pair of signals suitable for supplying to the next stage of the process.

A complex IQ frequency converter 703 combines the output from the IQ modulator 702 with a variable oscillator 704, implemented in the digital signal processing domain. The IQ converter 703 generates a modulated signal having a digital carrier frequency equal to the frequency, FV, of the variable oscillator 704.

The transmission signal from the digital signal processor 602 is supplied to the transmitter circuit 603, which contains a digital to analog converter 705, an analog IQ upconverter 706 and a radio frequency amplifier 707. The output from the digital to analog converter 705 is an analog version of the modulated signal imposed on the carrier of frequency FV. The analog IQ upconverter 706 combines this signal with the signal from the frequency synthesizer 604, having a frequency

FLO. The transmission band used for the satellite system is two gigahertz, thus the FLO is typically in the order of 2GHz. The analogue IQ upconverter 706 generates an output signal having a carrier frequency equal to FV + FLO. In an alternative embodiment, it is possible to generate a carrier frequency equal to FV - FLO, using an alternative design for the complex frequency converter 703.

By generating a low radio frequency in the range of zero to 200kHz using the variable oscillator 704 implemented in the digital signal processing domain, it is possible to provide virtually instantaneous very high frequency resolution, which is superimposed on a broad channel selection provided by the frequency synthesizer 604, having a channel step capability of 100kHz. Thus the loop settling time of the frequency synthesizer 604 is not compromised by the need to provide a close channel spacing of 12.5kHz. For example,

FLO = 2GHz = 2000000 Khz

FV = 125kHz

FV + FLO = 2000125 Khz

which may be instantly changed by the variable oscillator 704 in the digital signal processor 602:

FV = 147.5 Khz

FV + FLO = 2000147.5 Khz

a slightly slower change may be achieved using the frequency synthesizer 604, but this is still within the desired settling time because of its large frequency step of 100kHz:

FLO = 2000500 Khz

FV = 162.5kHz

FV + FLO = 2000662.5 Khz

in this example both FV and FLO were changed simultaneously, to achieve a large and yet highly accurate change in channel frequency, still within the desired settling time for the frequency synthesizer 604.

The output from the analog IQ modulator 706 is supplied to a radio frequency power amplifier 707, which supplies two gigahertz signals to the antenna 506 at a power of five watts.

The solution may be extended to reception, as shown in Figure 8. The incoming radio frequency signal from the antenna 506 is supplied to the receiver circuit 605. A modulator pre-amplifies the incoming radio frequencies and multiplies this signal by the output of the frequency synthesizer 604, which has a frequency equal to FLO. The frequency synthesizer 604 is arranged to provide a frequency which is about 140MHz less than the desired reception frequency. A signal 802 is thereby generated, which contains the desired signal, transposed to a carrier of 140MHz. This technique of transposing carrier frequencies is known as superheterodyning, usually abbreviated to superhet. The purpose of this transposition is to allow further amplification of the desired signal at a carrier frequency convenient for circuit design. Typically, superhet receivers provide improved rejection of unwanted signals, as well as several other advantages.

The carrier is thus transposed to an intermediate frequency of around 140MHz. After some amplification, this is then supplied to an analog IQ downconverter 803, which reduces the 140MHz intermediate frequency by IQ mixing with a 140MHz signal derived from a fixed analog oscillator 804. This results in an output signal 805. In known systems, this output would contain no channel frequency offset, or a small frequency offset due to doppler shifts arising from a relative velocity between the telephone and the satellite. However, in the preferred embodiment, the output signal 805 has been transposed to an intermediate frequency dependent on the fine channel offset in steps of 12.5kHz. Thus the signal 805 from the analog IQ downconverter 803 requires further complex mixing with the channel offset, in order to remove it completely from the radio frequency domain.

An analog to digital converter 806 converts the analog signal 805 to a digital signal 807, which is supplied to the digital signal processor 602. The digital signal 807 is processed by a complex frequency converter 808, arranged to mix signal 807 with

a signal from a variable oscillator 809, implemented in the digital signal processing domain. Thus, if the variable oscillator 809 is set to a frequency which matches the intermediate frequency in the signal generated by the analog IQ downconverter 803, the channel offset is removed and data can be retrieved by subsequent processes 810 and 811 in the digital signal processor 602. For example:

Rx frequency = 2,000,125 Khz

Synthesizer output, FLO = 2,140,000 Khz

First intermediate frequency 802 = 140,125 Khz

Second intermediate frequency 805 = 125 Khz

Variable oscillator 809, FV = 125 Khz

retuning by +12.5 Khz:

Rx frequency = 2,000,147.5 Khz

Synthesizer output, FLO = 2,140,000 Khz

First intermediate frequency 802 = 140,147.5 Khz

Second Intermediate frequency = 805 = 147.5 Khz

Variable oscillator 809, FV = 147.5 Khz

Thus the received channel is selectable in small increments by changing the frequency, FV, of the variable oscillator 809. Larger steps of plus or minus 100kHz are selectable by changing the frequency, FLO, supplied by the frequency synthesizer 604. The invention solves the problem of the loop settling time in the frequency synthesizer 604 by allowing large channel steps of 100kHz to be used, with smaller frequency offsets of 12.5kHz generated in the digital domain, by the digital signal processor 602.

The IQ modulation scheme used in the transmission chain shown in Figure 7, is detailed in Figure 9. The output from the IQ modulator 702 is a pair of I and Q signals. The frequency components in the Q signal are ninety degrees out of phase with the frequency components in the I signal. Several techniques are known for doing this in the digital domain, the most comprehensive being the Hilbert transform.

Thus the IQ modulator generates two paths 904 and 905, known as I, for immediate, and Q, for quadrature. This general approach allows further processing to be performed without the addition of an unwanted sidebands in the radio frequency domain. The I and Q signals 904 and 905 are supplied to two respective low pass filters 902 and 903, which perform a reconstruction of the digital waveform in the analogue domain, removing unwanted sample frequencies and other unwanted frequency components at the D-A output.

A complex IQ multiplier comprises four multipliers 906, 907, 908 and 909, in combination with two adders 910 and 911. The complex multiplier receives IQ signals representing the modulated data, and IQ signals from the variable oscillator 704. The result of multiplying these two pairs of signals in the discrete time domain is the addition of the two frequencies in the frequency domain, with high attenuation of unwanted sidebands. Generally, the digital I/Q processing performed in blocks 602 and 603 is implemented numerically in a digital signal processor or the like.

The resulting modulated IQ signals 912 and 913 are supplied from the digital signal processor 602 to the digital to analog converter 705 in the transmitter circuit 603. The digital to analog converter comprises two converters 914 and 916, with suitable anti-aliasing low-pass filters 915 and 917. The resulting analog IQ signal pair is supplied to the analog IQ upconverter 706, comprising two analog multipliers 918 and 921, supplied by respective analog IQ signals and an IQ signal pair derived from the frequency synthesizer 604. An analog adder 921 combines the IQ components for subsequent amplification in the radio frequency amplifier 707.

The effect of this final stage of analog IQ modulation is to superimpose the low radio frequency signal represented by the IQ components 912 and 913 upon the transmission frequency supplied by the radio frequency synthesizer 604. Again,

the use of an IQ upconverter ideally cancels the unwanted sideband and carrier. In practice the attenuation is limited to 30 to 40dB.

The analog IQ upconverter 706, shown in Figure 9, includes a phase splitter 919, for generating an IQ pair from the signal supplied by the frequency synthesizer 604. The phase splitter 919 is detailed in Figure 10. An input connection 1001 receives the signal from the frequency synthesizer 604, oscillating at frequency FLO. This input signal is supplied to a resistor 1002 and a capacitor 1003, which form a phase lag network, having a phase lag of forty-five degrees at the centre of the range of transmissible frequencies. In this case the centre of the frequency range is two gigahertz and values for R and C may be calculated by the formula:

$$R = 1 / wC$$

where $w = 2 \times PI \times$ frequency

The input signal is also supplied to a capacitor 1005 and a resistor 1006, which form a phase lead network, characterised by a phase lead of forty-five degrees at the same centre frequency of two gigahertz. Thus the output connections 1004 and 1007 have a phase difference of ninety degrees.

The use of such a simple circuit has advantages of simplified construction for use at high frequencies, but has a disadvantage of frequency-dependence. As a range of frequencies is to be transmitted, the network does not produce an exact phase shift of ninety degrees at frequencies other than those close to the centre frequency of two gigahertz. The output spectrum therefore contains small amplitudes of unwanted sidebands when the phase splitter 919 is operated at other than its central frequency. This is shown in Figure 11.

The wanted spectrum 1101 is centred around a frequency equal to FLO, the frequency of the frequency synthesizer 604, plus FV, the frequency of the variable oscillator 704, implemented in the digital signal processor 602. Non-linearity in the phase splitter 919 and elsewhere results in carrier leakage 1102 and an unwanted mirror image 1103 of the desired frequency spectrum, centred around the value of FLO minus FV. Fortunately, in satellite communications, the wanted signal has a

low variation in amplitude, due to the fact that radio signals are transmitted along the line of sight. Thus, although an unwanted image is transmitted, at twenty to thirty decibels below the desired signal, this does not interfere with reception.

Processes for demodulating a received signal shown in Figure 8 are detailed in Figure 12A and Figure 12B. In Figure 12A, radio frequency signals from the antenna circuitry are supplied to a mixer 1202. In practice this mixer consists of an integrated Gilbert Cell type mixer. The mixer 1202 is also supplied with the signal from the frequency synthesizer 604, oscillating at frequency FLO. Frequency components of the incoming radio frequency signal are mixed with the signal from the frequency synthesizer 604, thus generating a spectrum containing the sums and differences between the two inputs supplied to the mixer 1202. An intermediate frequency amplifier 1203 is used to amplify only those frequencies resulting from mixing which have a frequency of 140MHz. Thus by setting the frequency synthesizer to a frequency offset from the desired reception frequency by 140MHz, a difference frequency of 140MHz is generated which will be the only frequency amplified by the intermediate frequency amplifier 1203.

The resulting 140MHz intermediate frequency 802 is then split into two parts and supplied to the analog IQ downconverter 803. Here, the two paths are multiplied separately by corresponding IQ components generated by a phase splitter 1206. The phase splitter 1206 operates according to the circuit shown in Figure 10, but having plus and minus forty-five degree phase shifts at a frequency of 140MHz, instead of two gigahertz. The signal supplied to the phase splitter is supplied by the fixed frequency 140MHz oscillator 802. The IQ mixing is performed by multipliers 1204 and 1205, resulting in a further downwards transposition in frequency, to the range of up to a few hundred kilohertz.

In known receivers, the radio frequency carrier is removed at this stage, in other words it is converted to around zero frequency. However, this prevents the use of a sufficiently fast channel selection capability due to the design restrictions of frequency synthesizer phase locked loops. In order to ensure fast channel

selection, the final stage of radio frequency downconversion is performed by the digital signal processor 602. Thus the IQ signals 805 generated by the analog IQ downconverter 803 are supplied to the analog to digital converter 806. This comprises two converters 1207 and 1208, which supply digitized I and Q signals 807 to the digital signal processor 602.

The IQ downconversion process performed inside the digital signal processor shown in Figure 6 and Figure 8 is detailed in Figure 12B. The IQ signals 807 generated by the analog to digital converter 806 are supplied to respective digital band pass filters 1221 and 1222. Their outputs are supplied to a complex IQ multiplier comprising four multipliers 1223, 1224, 1225 and 1226. The complex IQ multiplier mixes the incoming IQ signals with a quadrature signal from the variable oscillator 809. This has the effect of removing the intermediate radio frequency component from the desired reception channel, resulting in the usual baseband I and Q channels for further demodulation processing. Typically, the down conversion is performed in a digital signal processor or the like.

The I and Q outputs 1231 and 1232 are supplied to the demodulator 810 and subsequent data reconstruction processes. In an alternative embodiment, the functionality of the bandpass filters 1221 and 1222 could be achieved by placing low pass filters in the paths of the I and Q outputs of the process shown in Figure 12B.

There are several important advantages to the invention, in addition to the main one of fast channel selection, which has been described. In a low orbit satellite phone system, considerable doppler effects result from the velocity of the satellite relative to the Earth-based mobile transceiver. Thus the frequency of signals received by the mobile transceiver from the satellite is variable, as are signals received by the satellite from the mobile transceiver, and might reach the value of channel spacing. In terrestrial cellular systems, doppler shifts of up to about 1kHz are encountered. In satellite systems, doppler shifts can be much greater than this. Typically, with low Earth-orbit systems, this doppler shift may extend to several

tens of kilohertz, depending on the position in orbit at the time communications take place.

In the frequency synthesizers shown in Figure 1 and Figure 2, frequencies are selected in steps; there is no provision for continuously variable frequency modification, as is required to compensate for the doppler shift encountered when communicating with non-geo-stationary satellites. The known solution is to provide a modified temperature compensated crystal oscillator TCXO 108, known as a voltage controlled temperature compensated crystal oscillator, or VCTCXO. A VCTCXO includes a varicap diode in the crystal oscillator circuit, which may be controlled by an external voltage. This voltage may be used to impart the necessary frequency offset for compensating for doppler shift. Another technique is to take the low frequency offset into account in the demodulation algorithm.

Varicap diodes do not have convenient or particularly stable characteristics, which makes the design and manufacture of sufficiently predictable and stable VCTCXO modules difficult and expensive. In practice, some of the non-linearities may be overcome by including the satellite in a frequency correction dialogue:

1 Satellite transmits to handset
2 Handset transmits to satellite
3 Satellite calculates received frequency
4 Satellite transmits correction factor to handset
5 Handset corrects varicap voltage

Thus errors in the frequency of the VCTCXO may be compensated by the highly accurate frequency measuring capabilities of the satellites on-board circuitry and computers. Nevertheless, the VCTCXO represents a weak link in the design of the handset.

The variable oscillators 704 and 809 shown in Figures 7 and 8 are implemented on a digital signal processor, and can thus provide very high frequency resolution. This allows the master oscillator in the frequency synthesizer 604 to be of a fixed

frequency type, and all doppler corrections can be performed by modifying frequency data supplied to the variable oscillators.

An additional source of difficulty when designing accurate frequency synthesizers operating in the gigahertz range, is the need to provide a reference oscillator manufactured to oscillate to a high level of accuracy. Typical these are quartz oscillators, and may provide a manufacturing tolerance of a few parts-per-million. When channels are to be selected in the gigahertz range to an accuracy of a few kilohertz, standard manufacturing tolerances become insufficient. The continuous variability of the variable oscillators 704 and 809, enables standard tolerance crystal oscillators to be used, as any frequency corrections can be performed by receiving correction signals from a satellite and modifying data supplied to the digital signal processor 602, on which the variable oscillators 704 and 809 are implemented.

A further and highly significant advantage of the invention relates to radio frequency interference generated within the mobile telephone handset itself. Traditionally a single quartz oscillator oscillating at around ten megahertz is used to control the frequency synthesizer. This high frequency is then divided down to the channel frequency spacing or a multiple of the channel frequency spacing. The quartz crystal is also used to control other parts of the circuit, providing clock pulses to the digital signal processor and microcontroller.

In many known designs, these circuits include their own phase locked loops so that a frequency convenient for communications may be generated by the quartz oscillator and other frequencies are generated internally by the digital signal processor and microcontroller, which are suitable for controlling their respective internal operations.

Thus the master quartz oscillator used in the mobile phone handset generates a signal which is distributed to several adjacent circuits. The oscillation waveform is a square wave, and contains many harmonics extending across several radio

frequency ranges which are involved in the processes of reception. Radio signals received by the handset from the satellite are considerably attenuated, and a highly sensitive receiver circuit is required in order to receive signals reliably. The weakness of the received signal is such that any radio frequency components generated by the quartz crystal may interfere with the reception process.

Given a fixed frequency master oscillator, it becomes possible to predict the frequencies of harmonics which will be generated, and thus which frequencies are to be avoided as reception channels. Thus, given the improved design, where the crystal is fixed and all frequency corrections are carried out by modifying a low frequency variable oscillator in the digital signal processor, it becomes possible to specify the channels which should be used for communication. Unusable reception frequencies can be predicted by calculating integer multiples of the frequency FREF, for example 13MHz, of the fixed master quartz oscillator:

$$\text{Unusable channel} = n \,.\, \text{FREF}$$

where n is an integer

Usable reception channels are then spaced between these frequencies:

$$\text{Usable channel} = (n + .5) \,.\, \text{FREF}$$

CLAIMS

1. A method of transmitting a digital input signal over a radio channel, comprising steps of:

processing said digital input signal in combination with a digital modulating signal to produce a digital intermediate signal;

converting said digital signal into an analog intermediate signal; and

processing said analog intermediate signal in combination with an analog modulating signal to produce a radio frequency output signal, wherein the frequency of said digital modulating signal and the frequency of said analog modulating signal are adjusted to change the frequency of said output signal.

2. A method of receiving a radio frequency signal, comprising steps of:

processing said signal in combination with an analog demodulating signal to produce an analog intermediate signal;

sampling said analog intermediate signal to produce a digital intermediate signal; and

processing said digital intermediate signal in combination with a digital demodulating signal to select a transmission channel, wherein said analog demodulating signal and said digital demodulating signal are adjusted to accommodate changes in the frequency of said received radio signal.

3. A method according to claim 2, wherein said intermediate signal is processed in combination with an additional analog demodulating signal before being sampled.

4. A method according to claim 2 or claim 3, wherein the resolution of the analog modulating or demodulating signal is wider than a channel spacing, to facilitate rapid frequency adjustments; and

individual channels are selected by a finer frequency resolution during said digital processing step.

5. A method according to any of claims 2 to 4, wherein the radio signals are susceptible to Doppler shifts and Doppler shift compensation is provided by adjusting the frequency of the digital modulating or digital demodulating signals in the digital signal processing domain.

6. Apparatus for transmitting a digital input signal over a radio channel, comprising:

processing means for processing said digital input signal in combination with a digital modulating signal to produce a digital intermediate signal;

converting means for converting said digital intermediate signal into an analog intermediate signal; and

processing means for processing said analog intermediate signal in combination with an analog modulating signal to produce a radio frequency output signal, including means arranged to adjust the frequency of said digital modulating signal and arranged to adjust the frequency of said analog modulating signal so as to change the frequency of said output signal.

7. Radio frequency receiving apparatus, comprising:

processing means for processing a received signal in combination with an analog demodulating signal to produce an analog intermediate signal;

sampling means for sampling said analog intermediate signal to produce a digital intermediate signal; and

processing means for processing said digital intermediate signal in combination with a digital demodulating signal to select a transmission channel, including means for adjusting the frequency of said analog demodulating signal and means for adjusting the frequency of said digital demodulating signal to accommodate variations in the frequency of said received signal.

8. Apparatus according to claim 7 including means for processing said intermediate signal in combination with an additional analog demodulating signal before said intermediate signal is sampled.

9. Apparatus according to any of claims 6 to 8, wherein the resolution of the analog modulating signal or the analog demodulating signal is wider than a channel spacing, to facilitate rapid frequency adjustments; and

individual channels are selected by a finer frequency resolution by the digital processing apparatus.

10. Apparatus according to any of claims 6 to 9, wherein radio signals are susceptible to Doppler shifts and Doppler shift compensation is provided by adjusting the frequency of the digital modulating or digital demodulating signals in the digital signal processing domain.

11. A method of transmitting and receiving radio signals substantially as herein described with reference to Figures 6 to 11, 12A and 12B.

12. Mobile telecommunications apparatus substantially as herein described with reference to Figures 3 to 11, 12A and 12B.

ABSTRACT

In a satellite mobile telephone a radio signal is transmitted by firstly generating (602) a digital input signal. The digital input signal is processed (703) in combination with a digital modulating signal (704) to produce a digital intermediate signal. The digital intermediate signal is converted (705) into an analog intermediate signal and said analog intermediate signal is processed (706) in combination with an analog modulating signal to produce a radio frequency output signal. Similarly, during reception, a received signal is processed in combination with an analog demodulating signal to produce an analog intermediate signal. The analog intermediate signal is sampled to produce a digital intermediate signal and said digital intermediate signal is processed in combination with a digital demodulating signal so as to select a transmitted channel. By performing processors partially in the analog domain and partially in the digital domain, it is possible to achieve rapid phase lock with a relatively narrow channel spacing.

Figure 7

Fig.1A.

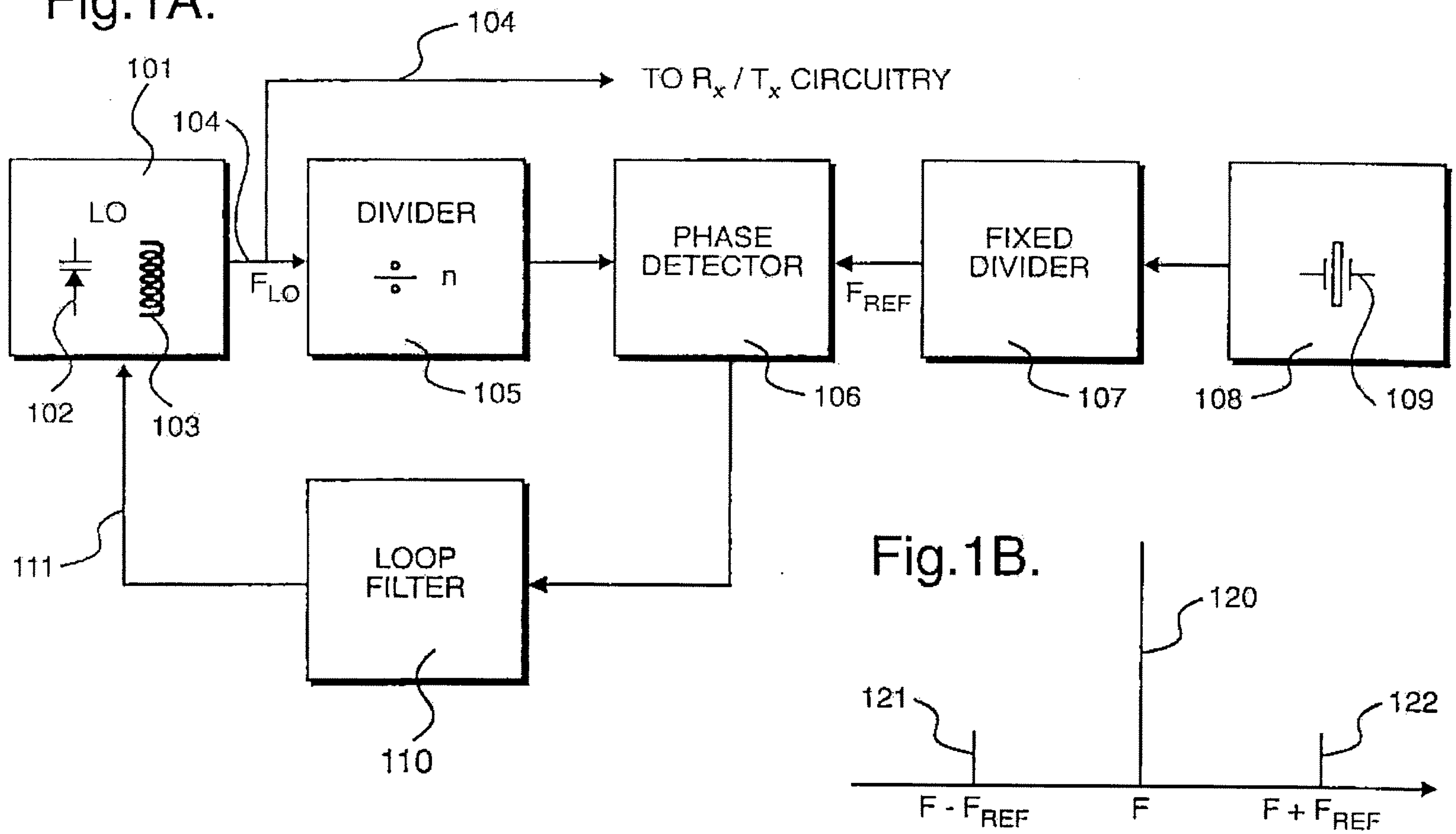
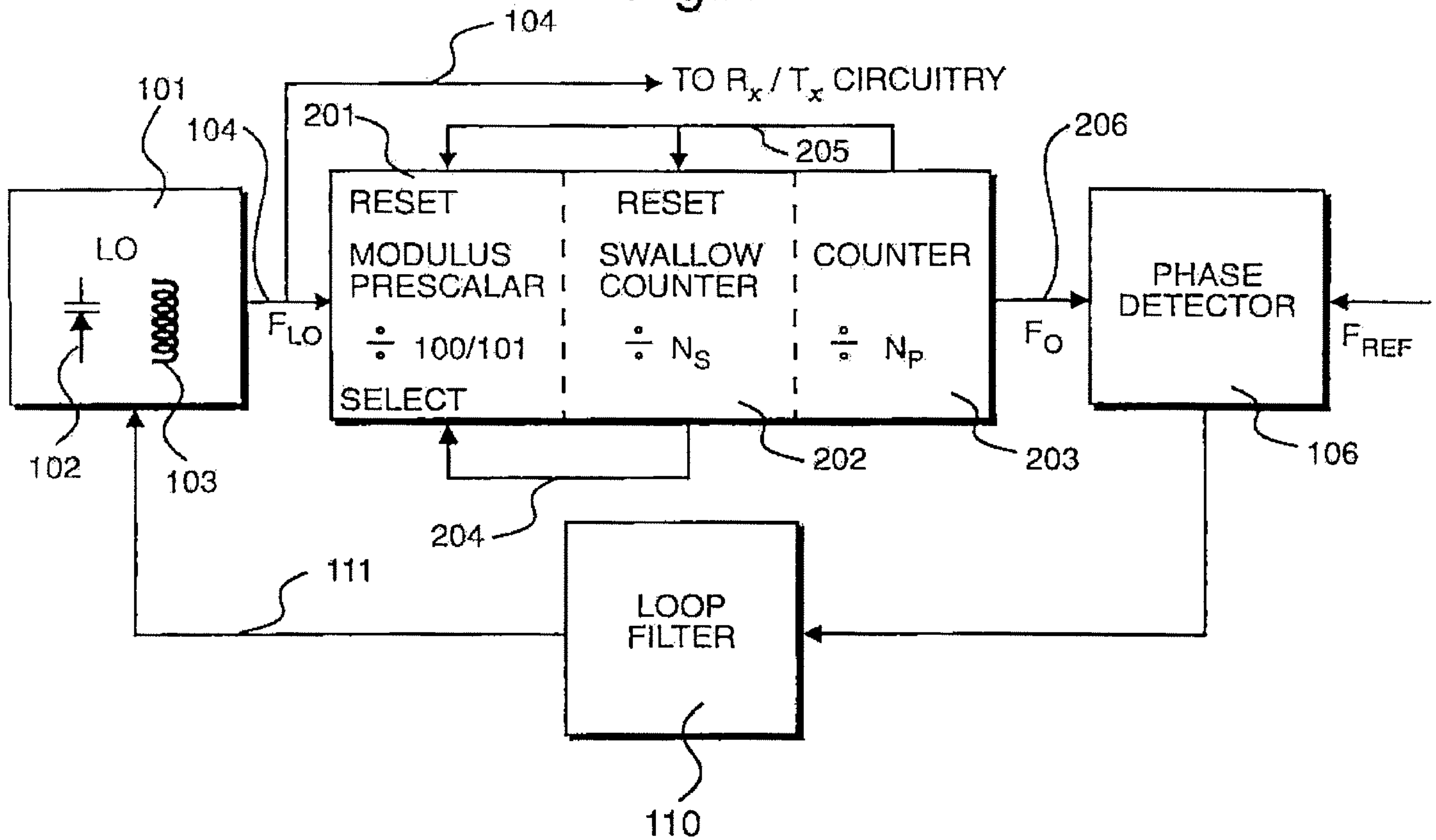

104
TO R_x / T_x CIRCUITRY
101
104
LO
DIVIDER
÷ n
PHASE DETECTOR
FIXED DIVIDER
F_{LO}
F_{REF}
102
103
105
106
107
108
109
111
LOOP FILTER
110
120
121
122
F - F_{REF}
F
F + F_{REF}

Fig.1B.

Fig.2.



104
TO R_x / T_x CIRCUITRY
101
104
201
205
206
LO
RESET
MODULUS
PRESCALAR
÷ 100/101
SELECT
RESET
SWALLOW
COUNTER
÷ N_S
COUNTER
÷ N_P
PHASE
DETECTOR
F_{LO}
F_O
F_{REF}
102
103
202
203
106
204
111
LOOP
FILTER
110

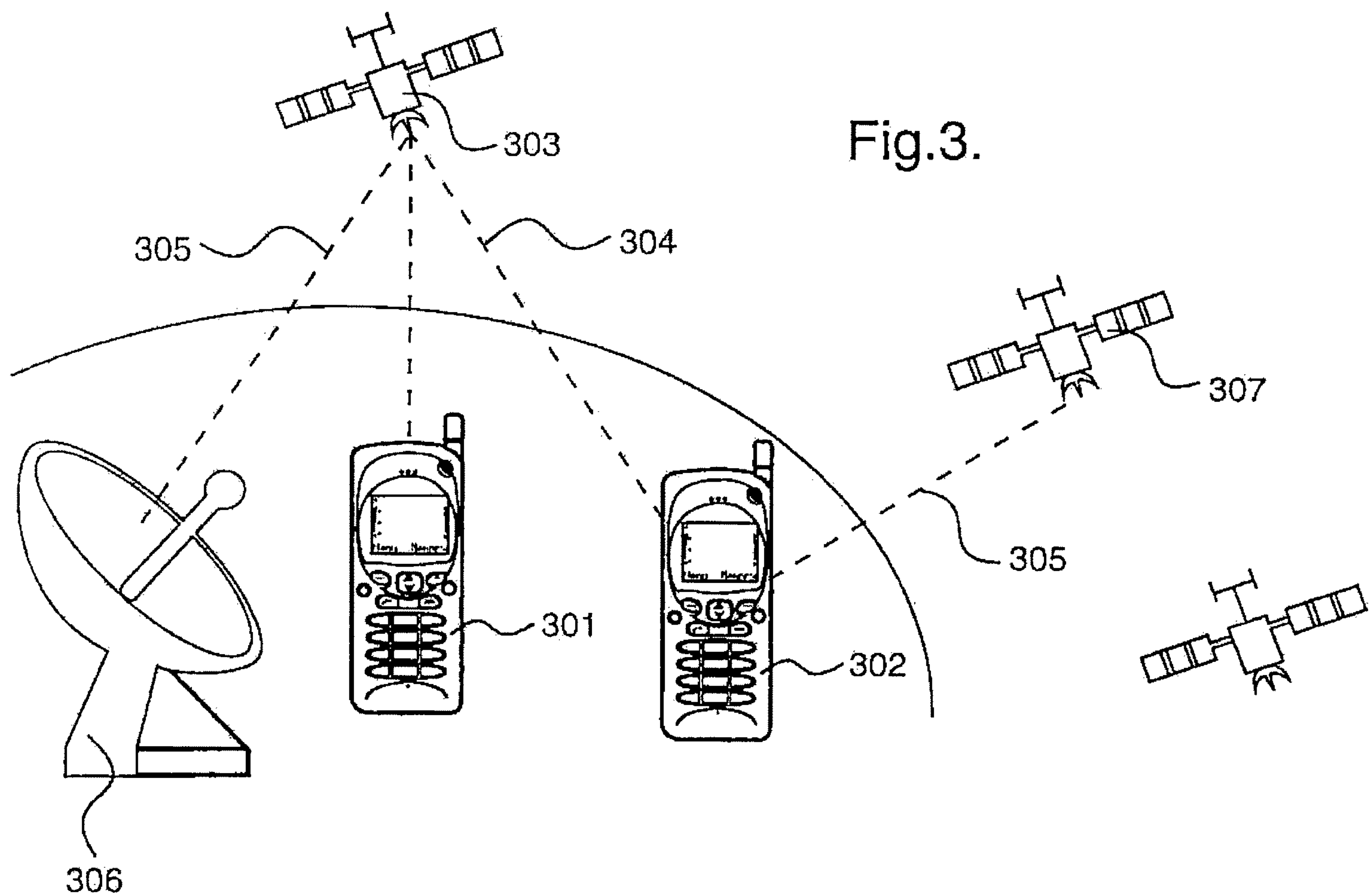


Fig.3.

Fig.4.

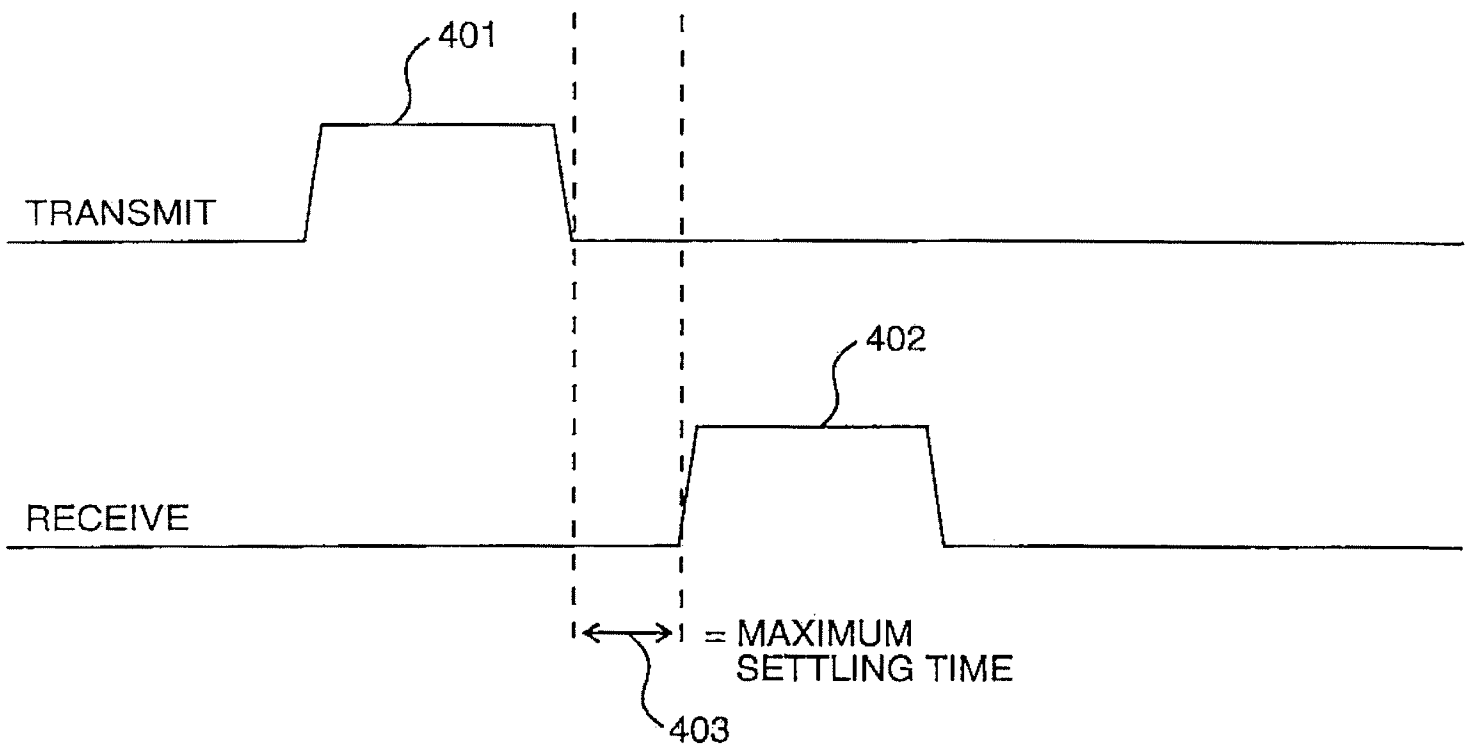


Fig.5.

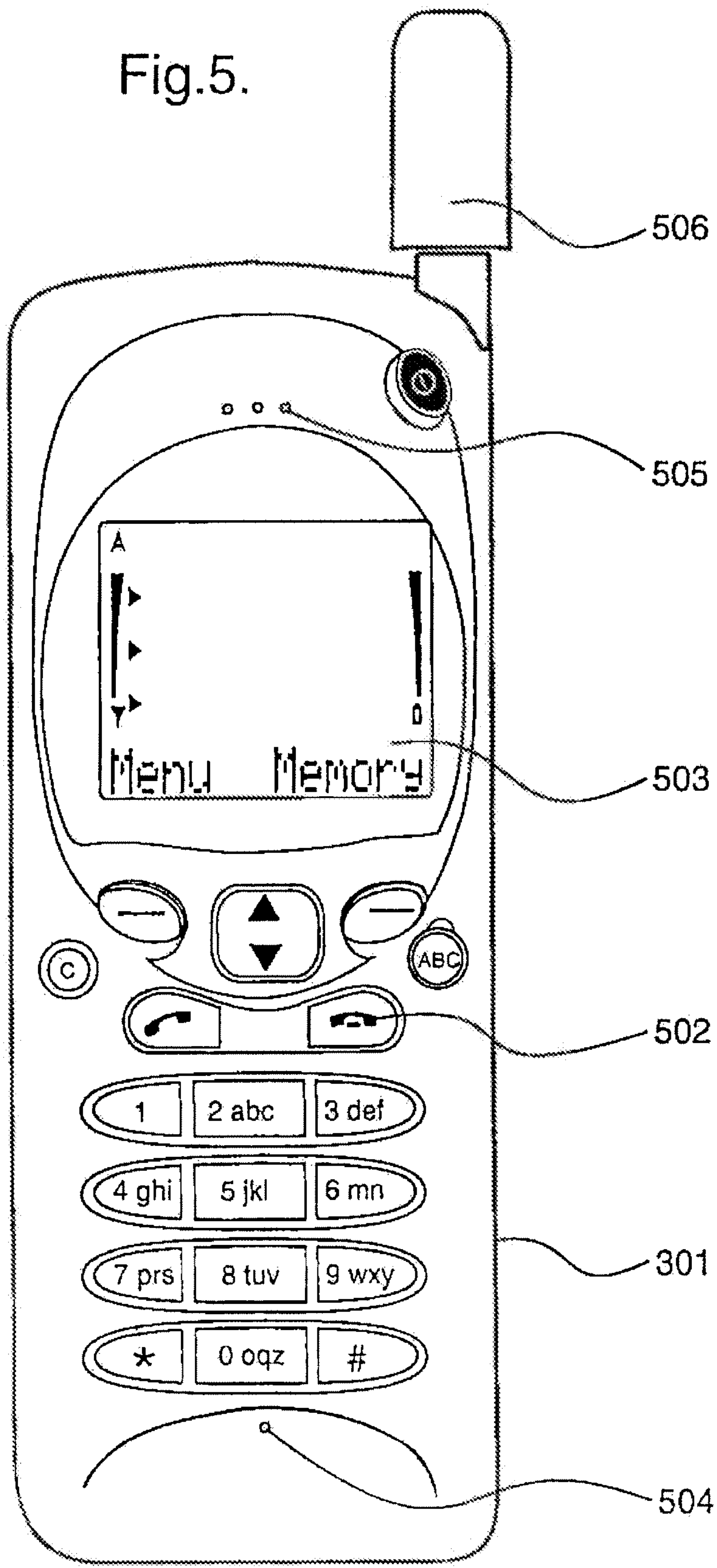
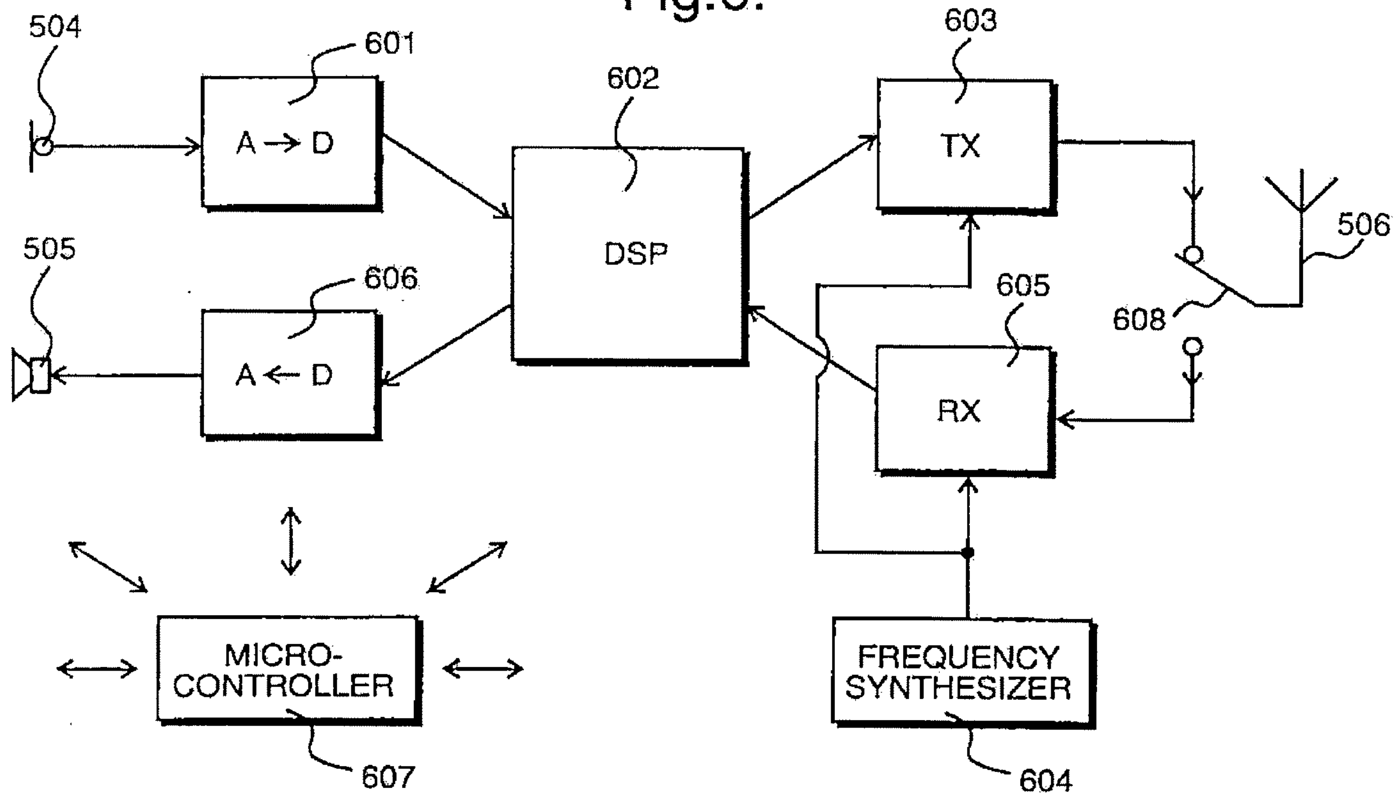

506
505
503
502
301
504
Menu
Memory
C
ABC
1
2 abc
3 def
4 ghi
5 jkl
6 mn
7 prs
8 tuv
9 wxy
*
0 oqz
#

Fig.6.



504
601
A → D
602
DSP
603
TX
505
606
A ← D
605
RX
608
506
MICRO-
CONTROLLER
607
FREQUENCY
SYNTHESIZER
604

Fig.7.

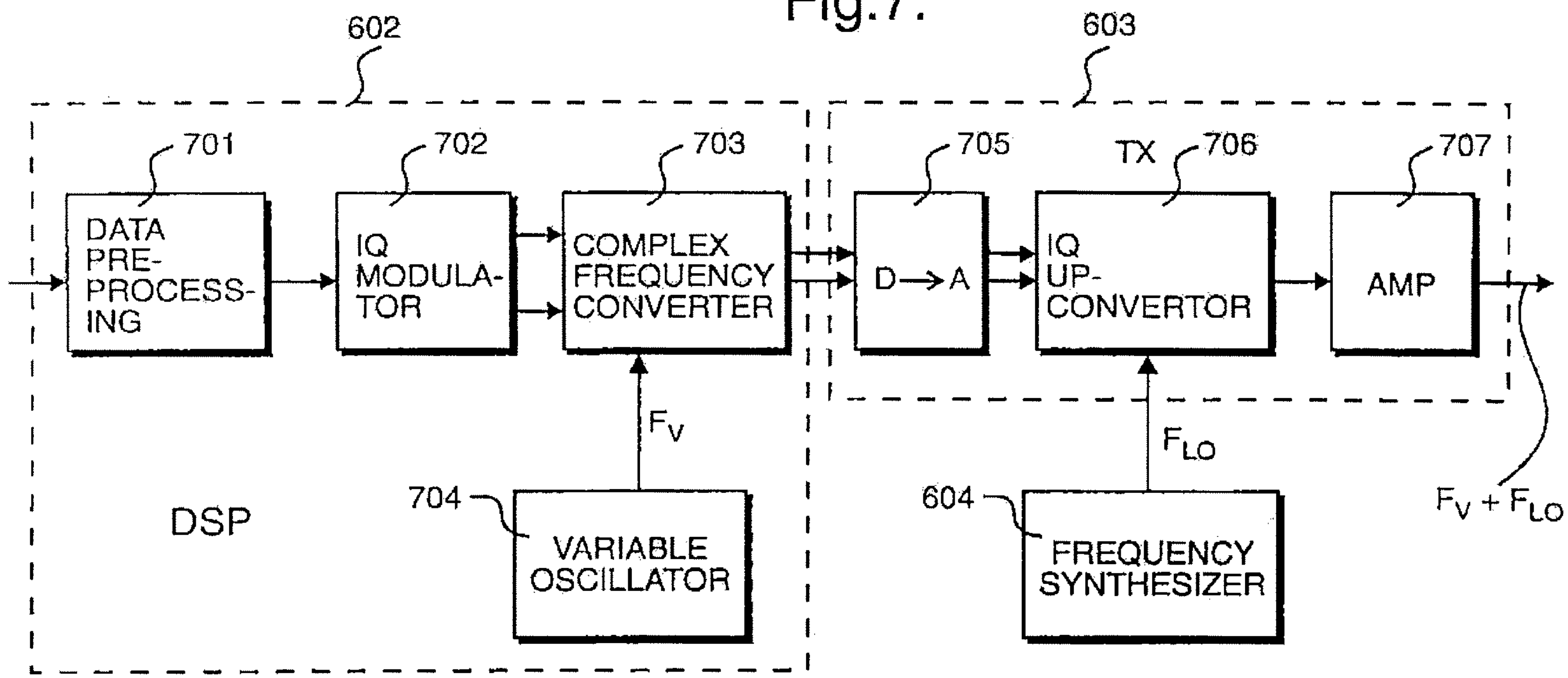
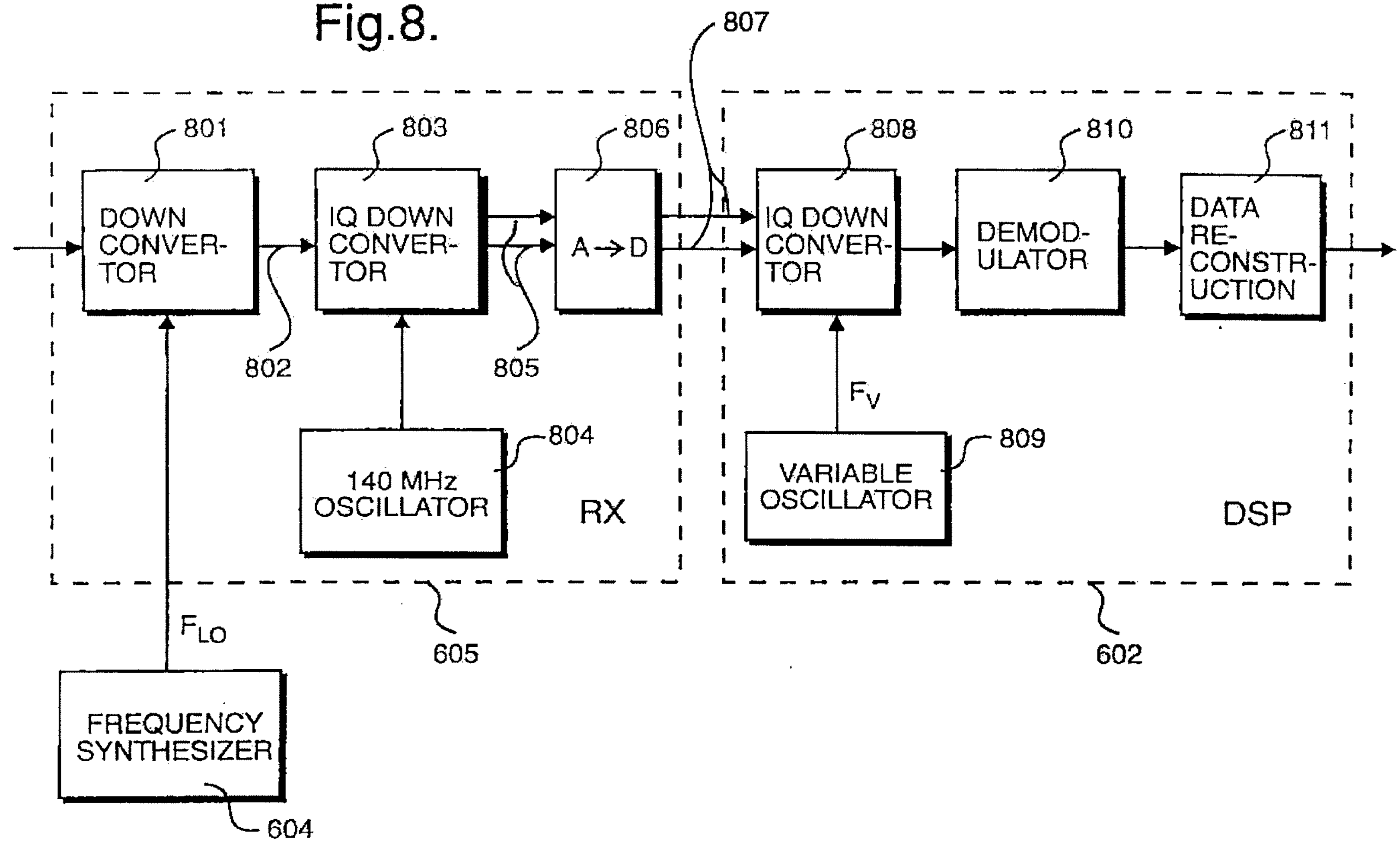
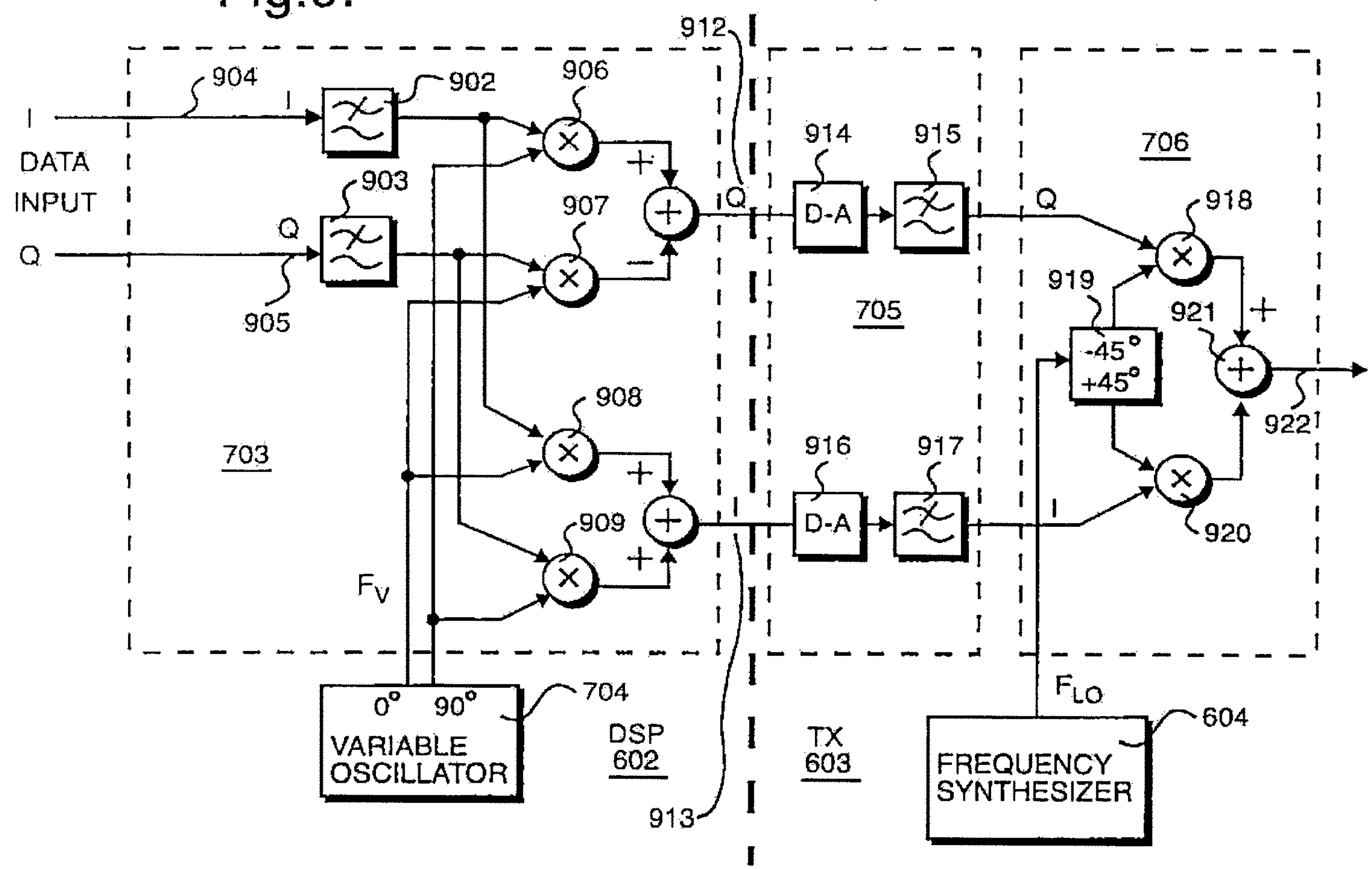

602
603
701
DATA PRE-PROCESS-ING
702
IQ MODULA-TOR
703
COMPLEX FREQUENCY CONVERTER
705
D→A
TX
706
IQ UP-CONVERTOR
707
AMP
F_V
704
VARIABLE OSCILLATOR
DSP
F_{LO}
604
FREQUENCY SYNTHESIZER
$F_V + F_{LO}$

Fig.8.



801
DOWN CONVER-TOR
802
803
IQ DOWN CONVER-TOR
805
806
A → D
807
808
IQ DOWN CONVER-TOR
810
DEMOD-ULATOR
811
DATA RE-CONSTR-UCTION
804
140 MHz OSCILLATOR
RX
F_V
809
VARIABLE OSCILLATOR
DSP
F_{LO}
605
602
FREQUENCY SYNTHESIZER
604

Fig.9.



I
DATA
INPUT
Q
904
905
I
Q
902
903
906
907
908
909
912
913
Q
I
703
0°
90°
VARIABLE
OSCILLATOR
704
F_V
DSP
602
914
915
916
917
D-A
D-A
705
TX
603
706
Q
I
918
919
-45°
+45°
920
921
922
F_{LO}
FREQUENCY
SYNTHESIZER
604

Fig.10.

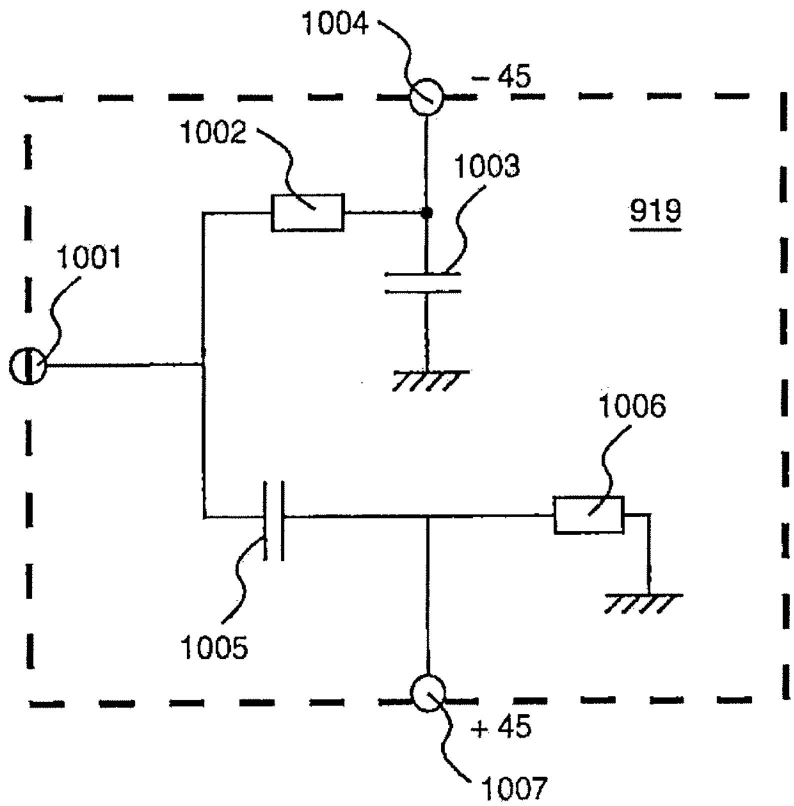

1004
- 45
1002
1003
919
1001
1006
1005
+ 45
1007

Fig.11.

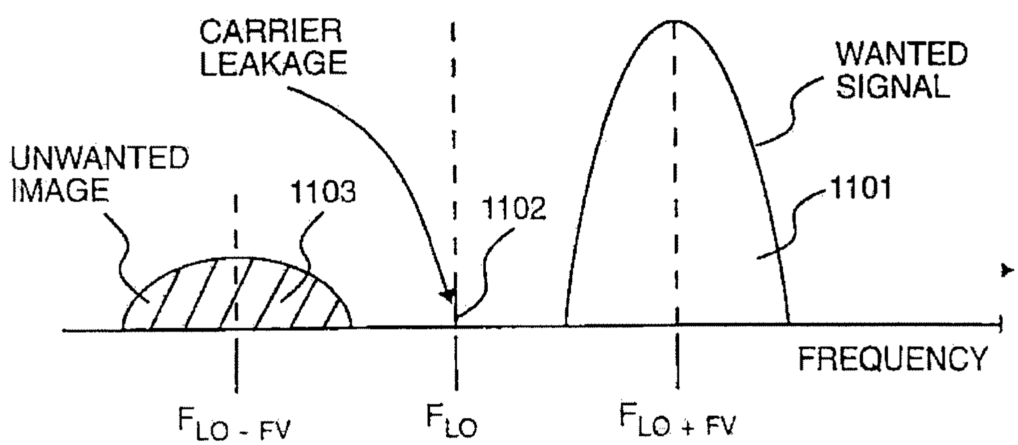
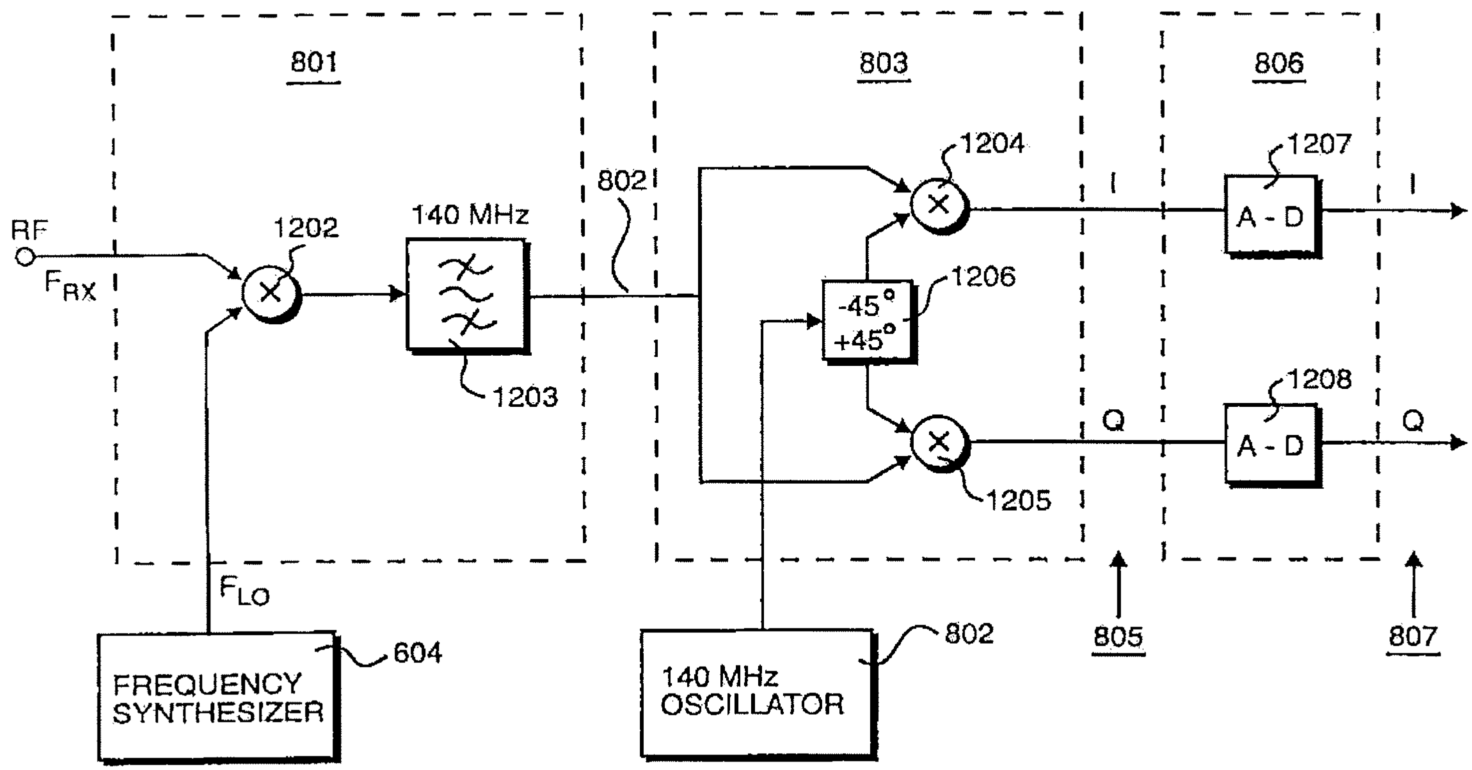
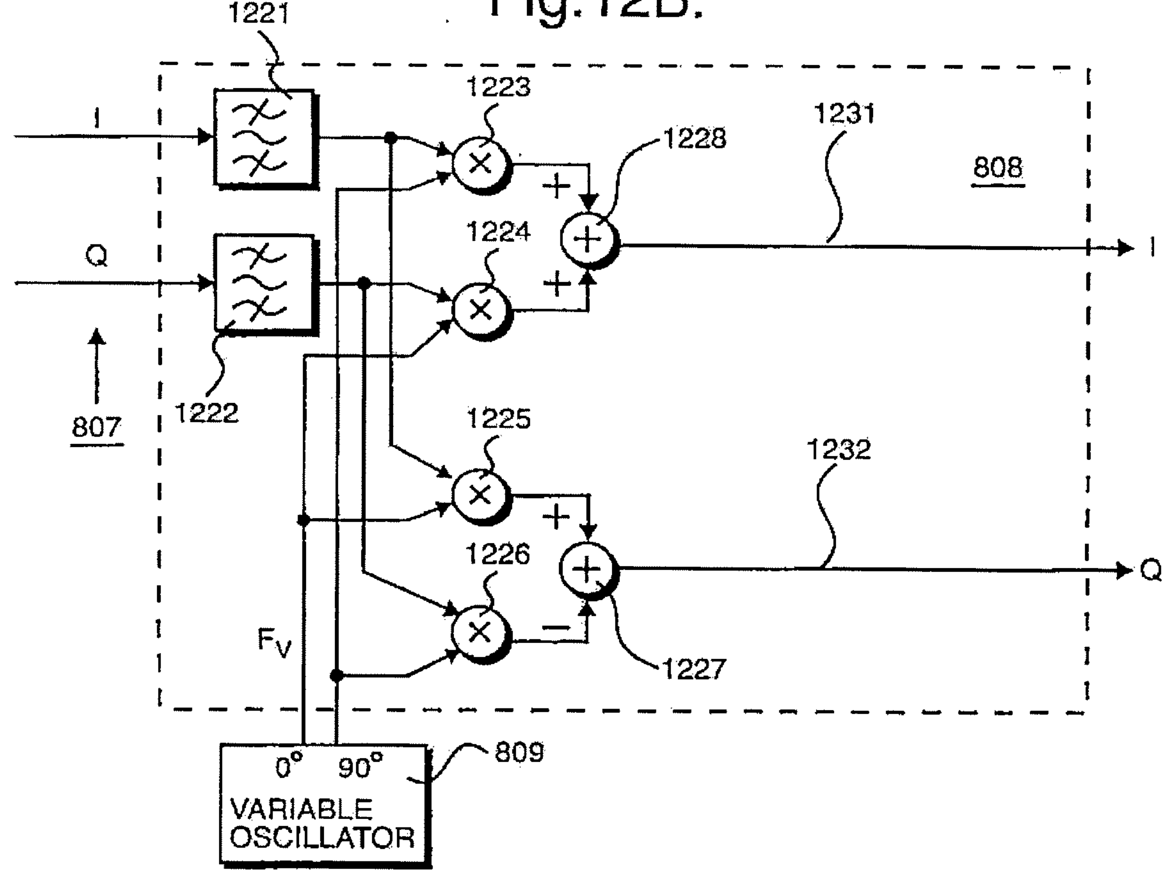

CARRIER
LEAKAGE
WANTED
SIGNAL
UNWANTED
IMAGE
1103
1102
1101
FREQUENCY
F LO - FV
F LO
F LO + FV

Fig.12A.



801
803
806
RF
F RX
1202
140 MHz
1203
802
1204
1206
-45°
+45°
1205
I
Q
1207
1208
A - D
A - D
F LO
FREQUENCY SYNTHESIZER
604
140 MHz OSCILLATOR
802
805
807

Fig.12B.



1221
I
Q
807
1222
1223
1224
1225
1226
+
+
+
−
1228
1227
1231
1232
808
I
Q
F_V
0°
90°
VARIABLE
OSCILLATOR
809